An Economical and Efficient HEATING SYSTEM FOR HOMES

Production Research Report No. 99

Agricultural Research Service
UNITED STATES DEPARTMENT OF AGRICULTURE

CONTENTS

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Washington, D.C. Issued September 1967

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington 25, D.C. 20402 - Price 20 cents

An Economical and Efficient Heating System for Homes

By Jerry O. Newman, *agricultural engineer, Agricultural Engineering Research Division*

INTRODUCTION

An ideal heating system must be low in cost and easy to operate. It must distribute the heat efficiently throughout the area and provide an even temperature at all times.

The objective of low cost was found in the first open fires, but they required constant attention, with low efficiency and very little comfort. To achieve efficiency, ease of operation, and better temperature distribution, more expensive systems have been developed. All improvements in heating equipment have not increased their cost, but the general trend has been better systems at higher cost. With heating becoming a larger part of the family budget, more effort has been directed toward lower cost methods of providing the desired environment in houses.

One of the systems that is directed toward this goal is the hot-air plenum. It utilizes the space under the structure as a duct for carrying the heated medium (air) to all the rooms in the house. Hot air is blown from the furnace into the space, creating a pressure. Registers in the floor at selected locations allow the warmed air to escape from the plenum into the room. Then this air is returned to the furnace where it is reheated and recirculated. It is a combination of a hot air and a radiant system. Warm air moving under the floor stores heat in the flooring members; this provides a large warm surface that radiates heat into the room. Warm air escaping from the plenum mixes with room air and increases the room air temperature.

The combination of a warm air and radiant heating system dates back to the early Roman structures, which utilized the Hypocaust Piers to form "Hypocaust Ducts" for distribution of heat under the floors and through columns. It was used primarily to heat the baths in the more luxurious structures and probably never evolved as a recommended heating system because it was expensive and probably inefficient. The warm-air radiant system thus disappeared.

In recent years several researchers have directed their efforts toward plenum floor systems.

G. J. Stout [1] of Pennsylvania State University developed a plenum over a concrete slab. Metal trusses (W-shaped) about 4 inches tall supported the 2 by 4 joist and subfloor above the slab. He recommends several alternate means of supporting the floor (treated wood blocks, bricks, concrete blocks, or perforated metal studs). Warm air from the plenum is diffused into the room through a long narrow slot between the exterior walls and the floor. He claims effective heating and adaptability as the chief advantages of this system.

An extensive study was conducted by John W. Talbott [2] of Washington State University in cooperation with the National Lumber Manufacturers Association. This study was directed toward wood floors that would allow low-profile construction [3] with an appearance similar to that of slab on grade construction. He did not use a concrete slab for the bottom of his plenum; however, he did recommend a plastic ground cover to prevent moisture buildup in the floor framing. He found temperatures throughout the house to be extremely uniform. The temperature span throughout the house was usually within 2°F.

In Talbott's report, he evaluates several low-profile floor systems that have been developed. Most of these lend themselves to under-the-floor heat distribution.

1. The "Andy Place" crawl-space plenum utilizes prestressed concrete grade beams and 6-inch steel I-beams to support a 1⅛-inch plywood deck.

2. The foamed-core slab is a sandwich panel with polystyrene core and asbestos-cement skins. The insulated core reduces heat loss through the slab and thus allows the inside

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[1] Stout, G. J. plenum floor system for basementless houses. Pa. State Univ., Better Building Rpt. 4., 22 pp., illus. University Park, Pa. 1960.

[2] Talbott, J. W. low profile wood floor systems. Wash. State Univ. Inst. Technol. Bul. 277, 77 pp., illus. Pullman, Wash. 1963.

[3] Low-profile construction is a term that describes the relative dimensions of a house. A low-profile house is one that is built close to the ground and is relatively long in length and short in height.

surface temperature to be maintained at a higher level.

3. Carl Boester's 1-day foundation utilizes concrete blocks and steel rods to build a grade beam to support the floor above the ground.

4. "Insta floor" is the trade name for a prefabricated floor system developed for crawl-space construction.

5. "Trofdek," "2-4-1" plywood, and "Plylumber" flooring are some of the systems that utilize combinations of plywood and dimensional lumber.

Canada's National Home Builders Association developed a plenum in their Mark III research house.[4] This system uses ⅝-inch holes 1 inch on center for diffusing air into the living area. Their work concentrated on the heating unit and the ventilation associated with this unit.

A report from Kansas Engineering Experimental Station [5] shows the results of a survey on the "Effect of Heated Floor Temperature on Comfort." Since a warm floor is one of the features of a hot-air plenum, one must know what floor temperatures are applicable. Tests showed that length of exposure and body exertion affects the maximum comfortable foot temperature. Floors have been found to be comfortable at temperatures as high 100°F., but on other occasions temperatures as low as 88° have been determined to be uncomfortable.

The National Fire Prevention Code [6] has set up standards for concealed-space plenums. They restrict the use of such a system to single-story structures. They limit the chamber height to 24 inches. They limit construction materials to those with a flame-spread rating of 200 (that of 1-inch lumber), and they restrict the furnace bonnet temperature to 150°F. They require blind ducts, deflection receptacles, and other items that are cumbersome and useless when a maximum bonnet temperature of 150° is allowed.

Some of the advantages that are claimed by most researchers for their plenum systems are:

1. Uniform temperature distribution;
2. Comfortably warm floors;
3. Protection of water and sewer lines from freezing;
4. Heating unit installation is usually lower in cost;
5. System is easily adaptable to several types of heating units and types of fuel;
6. With deep plenums, most of the advantages of the crawl-space type construction are accomplished.

Some of the disadvantages are:

1. The National Fire Code places many restrictions on a hot-air plenum;
2. Entire operation dependent on the blower operation;
3. House must be underpinned;
4. Access doors to plenum or crawl space must be kept closed;
5. Direct opening from living area to plenum;
6. A cold house does not warm up fast;
7. More fuel may be necessary.

HOT-AIR PLENUM

Low-Profile Plenum

Introduction

A new bedroom built onto experimental house D at the Agricultural Research Center, Beltsville, Md., provided an opportunity to compare a plenum heating system installed in the addition with the perimeter-duct heating system existing in the original part of house (fig. 1).

Installation of Plenum

The plenum was developed on a 4-inch concrete slab that was insulated and moisture proofed according to common practice (fig. 2). Regular brick placed on their flat face in a bed of mortar acted as spacers to support the floor and its frame 2 inches above the slab. The frame was constructed of 2- by 4-inch timbers laid flat. The subfloor was 1⅛-inch tongue-and-groove plywood in 4- by 8-foot sheets. Vinyl tile was glued to the plywood subfloor as a decorative and wearing surface.

The perimeter-duct system already in use was tapped to obtain a heat supply for the plenum (fig. 3). Registers were omitted because they concentrate the heat flow into the room and create air currents. To overcome this undesirable feature (registers), which is common to most heating systems, a perimeter slot was designed to distribute air flowing into the room (fig. 4). A long, narrow opening was developed between the floor and outside wall by a loose-fitting subfloor. This opening ranged from 0 to ½ inch in width, but its effective width was further reduced by the baseboard

[4] Anonymous. HERE ARE THREE NEW IDEAS FROM A NEW RESEARCH HOUSE. House and Home (May), p. 251, illus. 1961.

[5] Nevins, R. G., and Flinner, A. O. EFFECT OF HEATED-FLOOR TEMPERATURES ON COMFORT. ASHAE Jour. Sect., Heating, Piping and Air Conditioning (October), pp. 149–153, illus. Manhattan, Kans. 1957.

[6] Anonymous. NATIONAL FIRE CODES. BUILDING CONSTRUCTION FACILITIES. Natl. Fire Protection Assoc. v. 4, pp. 90B-18-21. Boston, Mass. 1963–64.

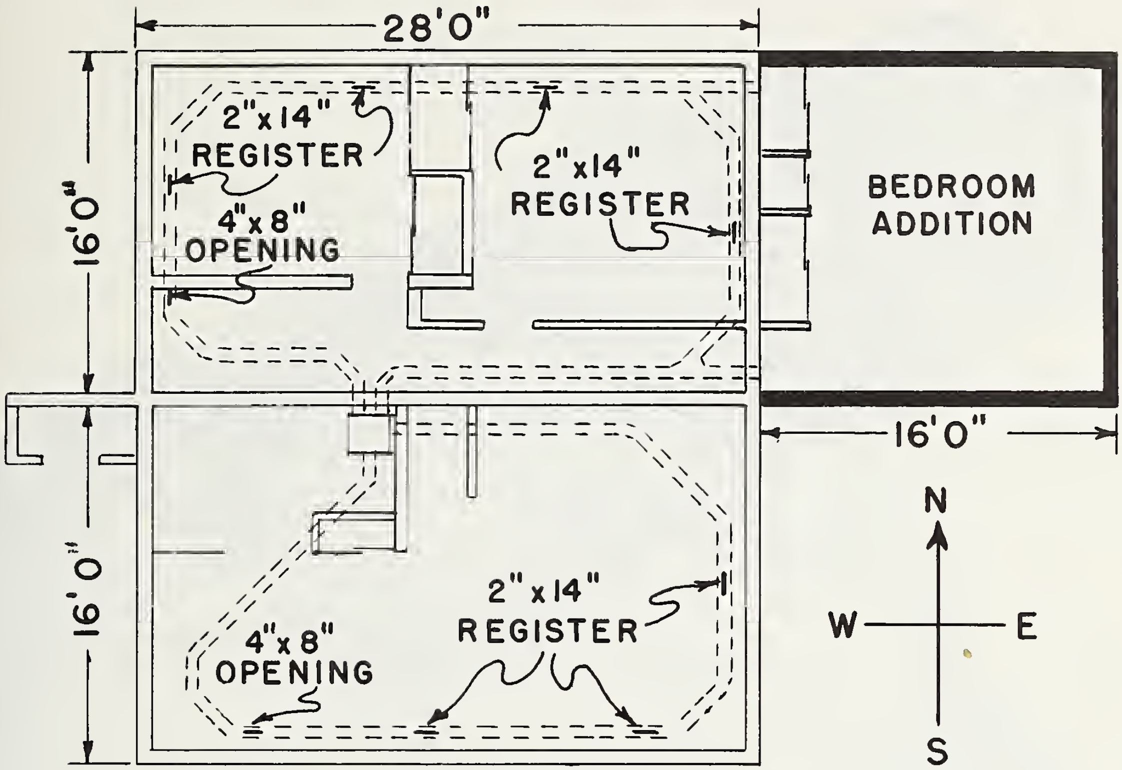

FIGURE 1.—Schematic of house D floor plan.

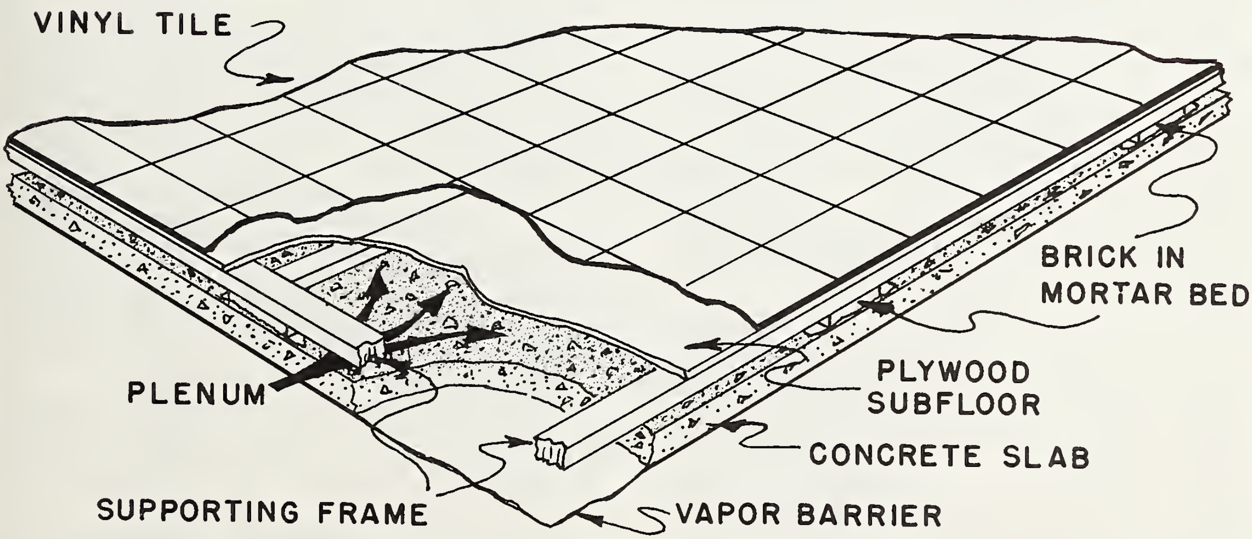

FIGURE 2.—Schematic of hot-air plenum construction in addition to house D.

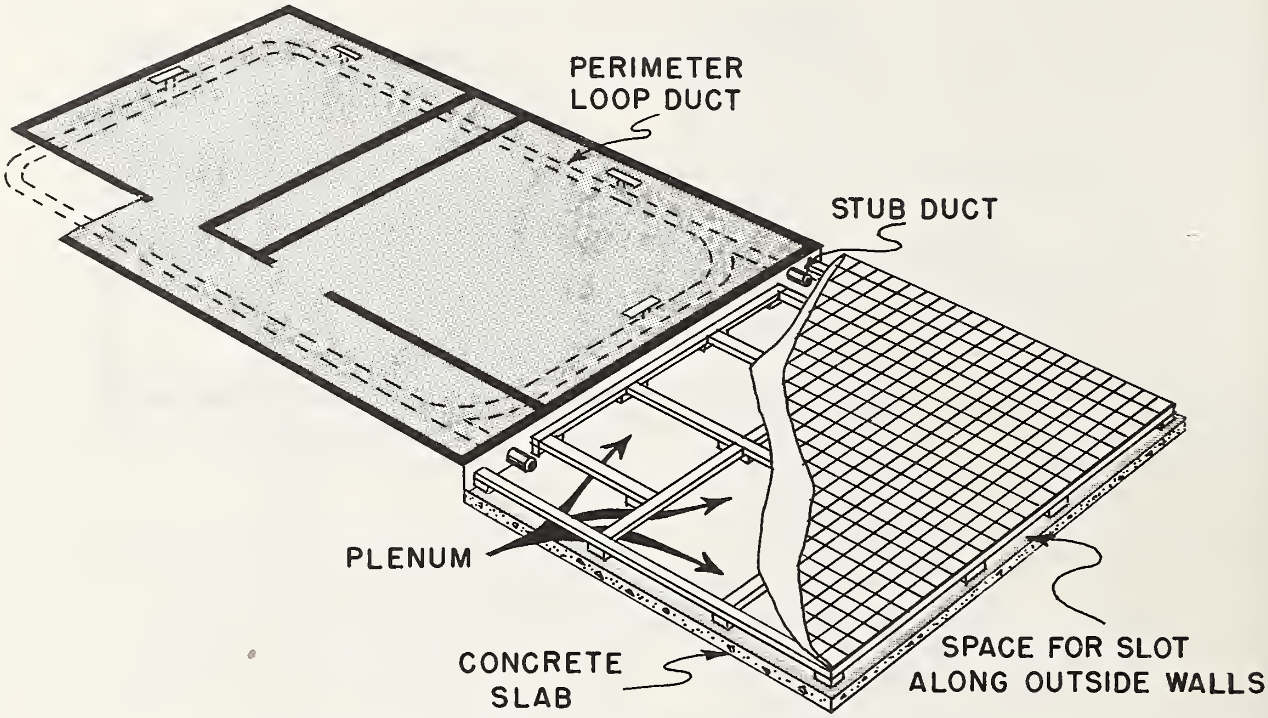

FIGURE 3.—Schematic of perimeter-loop ducting and underfloor plenum in house D.

that shielded it. Air entering the room through this opening was evenly distributed and annoying air currents were avoided.

Testing Periods and Conditions

Tests were conducted over a 3-year period in house D.

Each room is different in orientation, construction of walls, and exposure (fig. 5).

The master bedroom is on the northwest corner of the house. It has two exposed walls, one to the north and one to the west. Each exposed wall has a large window extending from the floor to the plate.

The center bedroom has one wall exposed on the north side. It has one window with the same dimensions as those in the master bedroom.

The new bedroom has three exposed walls, one to the north, one to the south, and one to the east. One medium-size window is located near the top and center of the north wall. One long flat window is located in the upper center of the south wall.

The north wall of the new bedroom is SCR brick[7] with 2 inches of furring, 2 inches of fiberglass insulation, and a ⅜-inch gypsum board interior surface. The east and south walls are standard 2- by 4-inch framing 16 inches on center with 2 inches of fiberglass insulation. The exterior walls are textured plywood and the interior is ⅜-inch gypsum board.

Originally the walls of the master and the center bedrooms consisted of one layer of SCR brick. These walls were not altered during the first season.

During the second year, the walls of the center and the master bedrooms were insulated and finished in successive steps (p. 10) in an effort to have more uniform testing conditions in the three bedrooms. Each step provided a new series of tests.

The test for the third season was designed to confirm data collected during the 2 previous years.

The heating system in the master and the center bedroom is a perimeter loop with air traveling in the loop in the direction of least resistance. The heater is an oil furnace and it is operated by on-off wall thermostat.

The duct was tapped in two places to obtain a supply of heated air for the plenum of the new bedroom (fig. 3). Other outlets were located under each window in the master bed-

[7] SCR brick have a nominal size, which is 12 inches long, 6 inches wide, and 2⅔ inches thick. "Brick and Tile Engineering," by Harry C. Plummer, Structural Clay Products Institute, Washington, D.C. 1962.

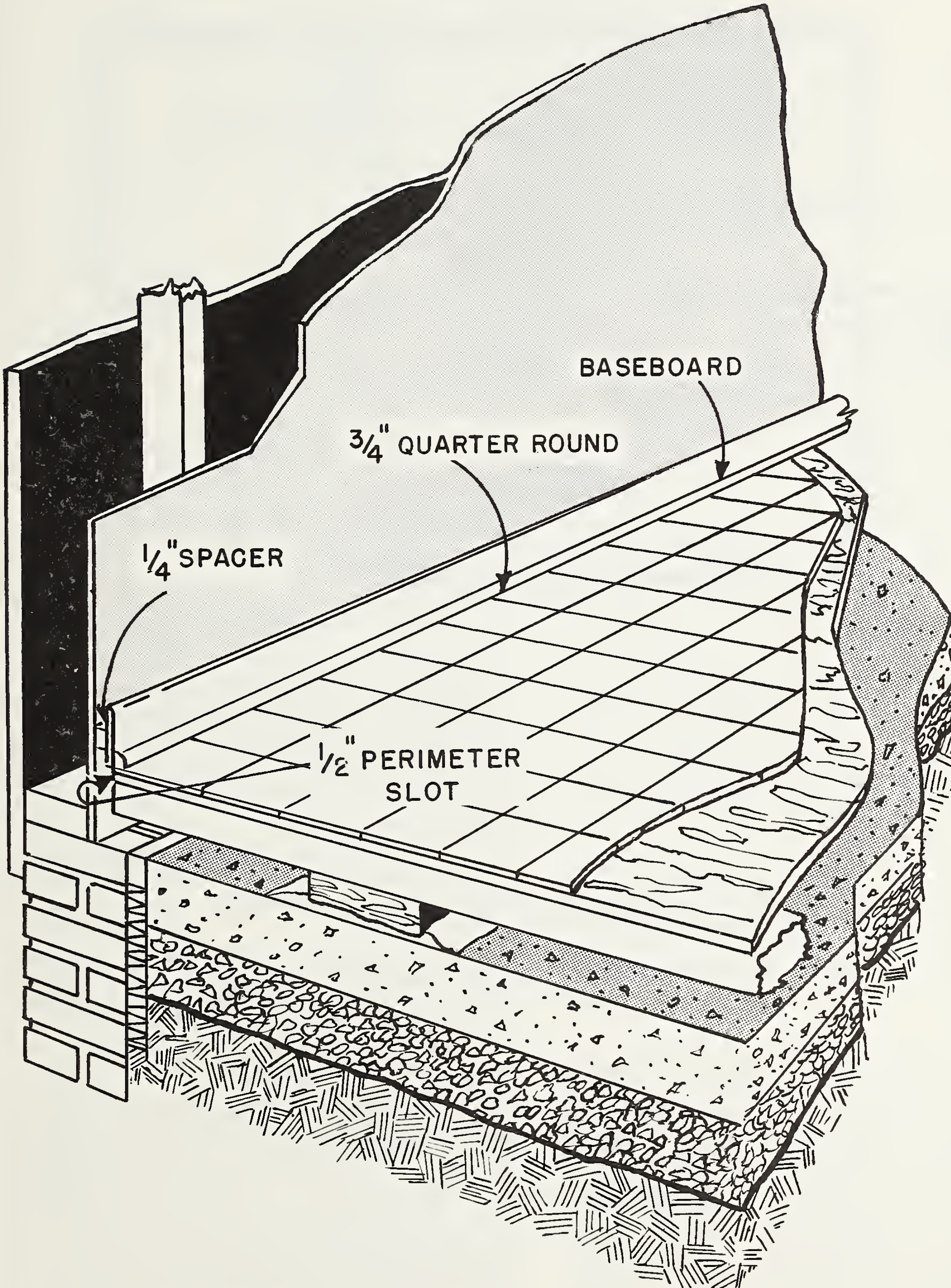

FIGURE 4.—Schematic of air discharge slot for underfloor plenum in house D.

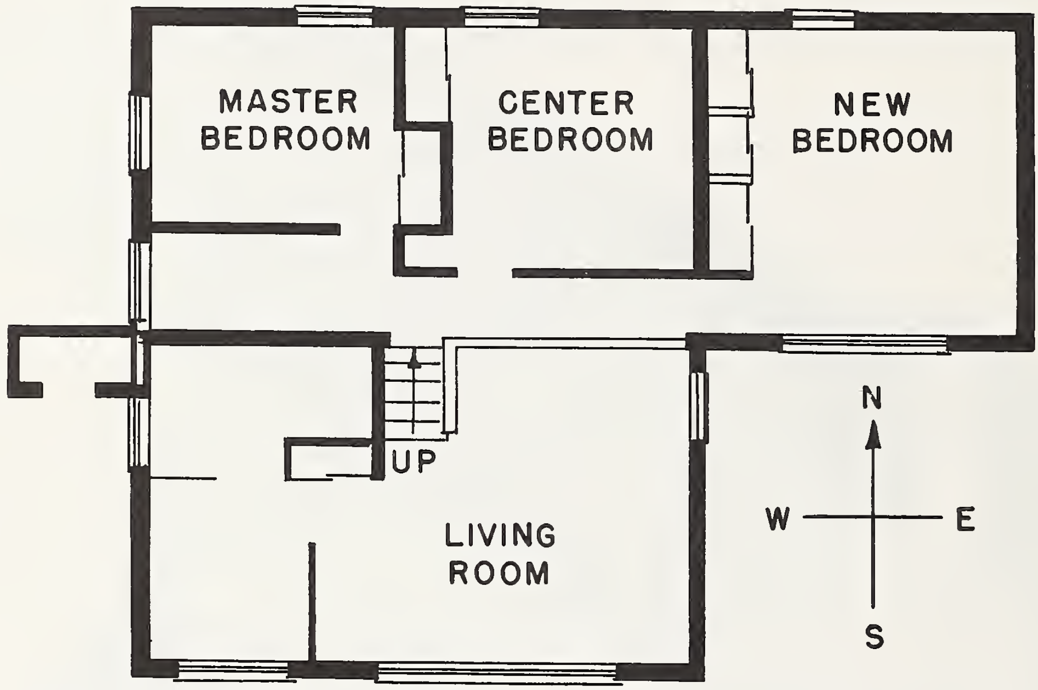

FIGURE 5.—Floor plan of house D, showing the orientation of each of the rooms being tested.

room (two each), one in the bathroom, and under the window and along the east wall of the center bedroom (two each). Many variables (air temperatures and velocity, inside temperature, and ground temperature) were presented throughout the testing season.

Objectives of Tests

The objectives of these tests were to study the performance of heated plenum as a system for house heating, to determine its faults and its merits, to determine if and how it can be improved, and to test ideas that suggest better performance.

First-Season Tests

Testing procedure.—To determine uniformity of heat distribution in the room or rooms from time to time and point to point, temperatures were measured at three elevations in each room (4, 48, and 90 inches) and about 1 foot from the outside wall. These temperatures were sensed by copper-constantan thermocouples, which were supported at the proper elevation by telescoping aluminum poles.

Thermocouples were also located in the plenum chamber, in the soil under the chamber, and at various other points in the structure.

Temperatures were recorded by a 16-point potentiometer that was scheduled to record every 2 hours. Since there were more than 16 thermocouples in the structure and all thermocouples could not be recorded at the same time, it was necessary to group the thermocouples for alternate tests.

Results of tests.—The first series of tests were begun on February 21, 1965, to determine the temperature distribution in the plenum and in the slab.

The temperatures recorded by the four thermocouples located in the corners of the plenum are plotted in figure 6, *A*. There was considerable variation in plenum temperature from point to point at the same time and from time to time at the same point.

The slab temperatures 4 inches below the plenum (at the base of the slab) in each corner of the room addition are plotted in figure 6, *B*. The variation from point to point was fairly large, but each point showed little fluctuation from time to time. The temperatures were found to be higher where the air entered the plenum, and these temperatures dropped off in the corners away from the heat supply. The temperatures along the south wall were higher than those along the north wall. This was

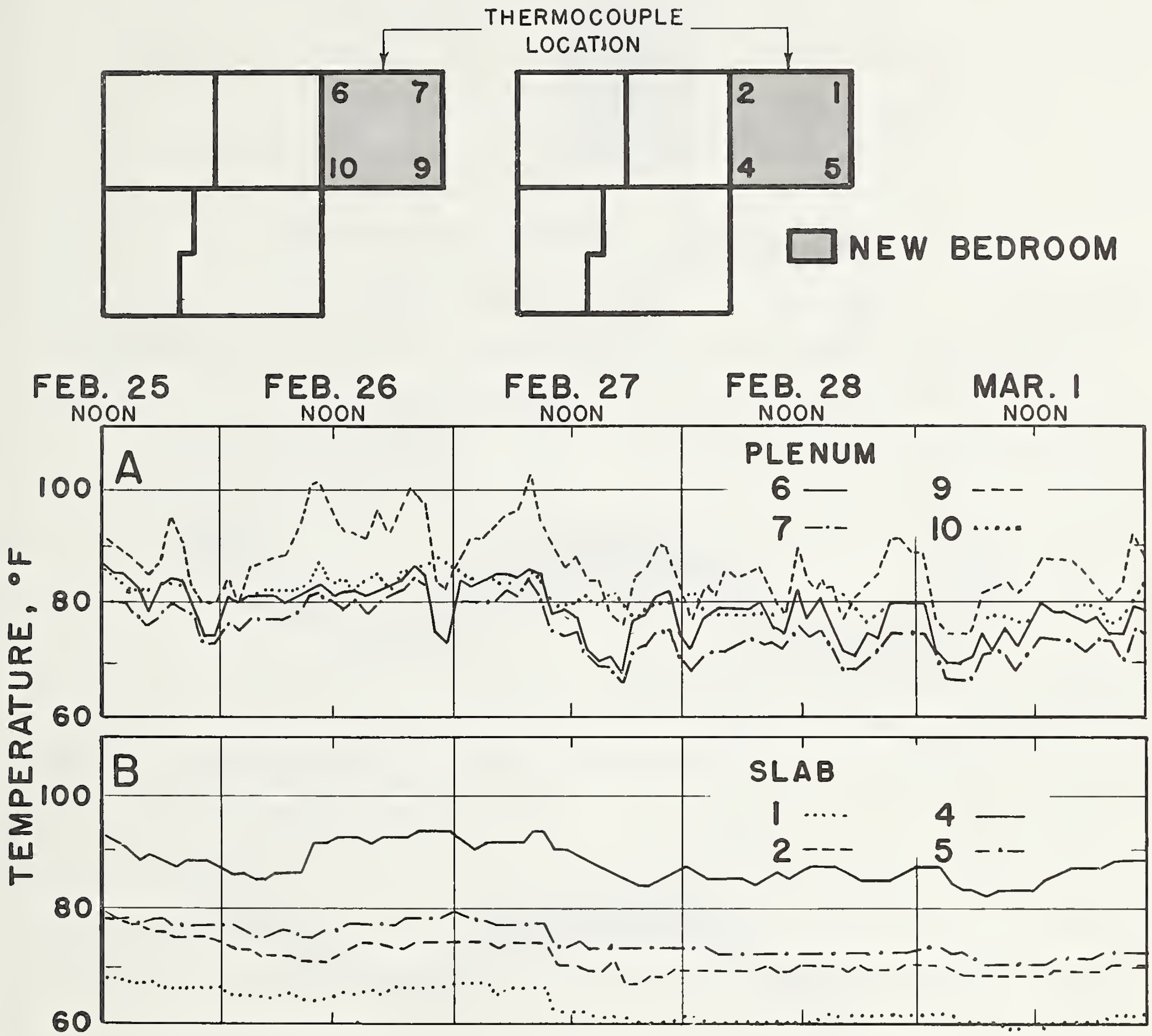

FIGURE 6.—Temperature in bedroom addition to house D: *A*, In corners of plenum chamber; *B*, in corners at base of concrete slab.

probably due to the shorter run of piping from the furnace to the plenum on the south side.

Figure 7 is a comparison of the plenum and the slab temperatures for one corner of the plenum. The air temperatures fluctuated considerably, but the slab, with a greater mass, showed little fluctuation and remained about 10° F. colder than the air temperature. In case of system failure the slab would act as a heat source to help maintain the house temperature.

In the second series of tests, the air temperatures at 4, 48, and 90 inches above the floor in four rooms of the house were recorded. These tests were to compare the temperature distribution of the room with the hot-air plenum with that of the rooms with the perimeter loop.

The temperatures in the new bedroom and the living room are plotted in figure 8, *A*. The temperatures in both rooms varied in a daily cycle. The differential between the temperatures at the 4-inch and the 90-inch level was greater in the living room, and the hourly fluctuation was sharper in the living room. The new bedroom showed more uniform tempera-

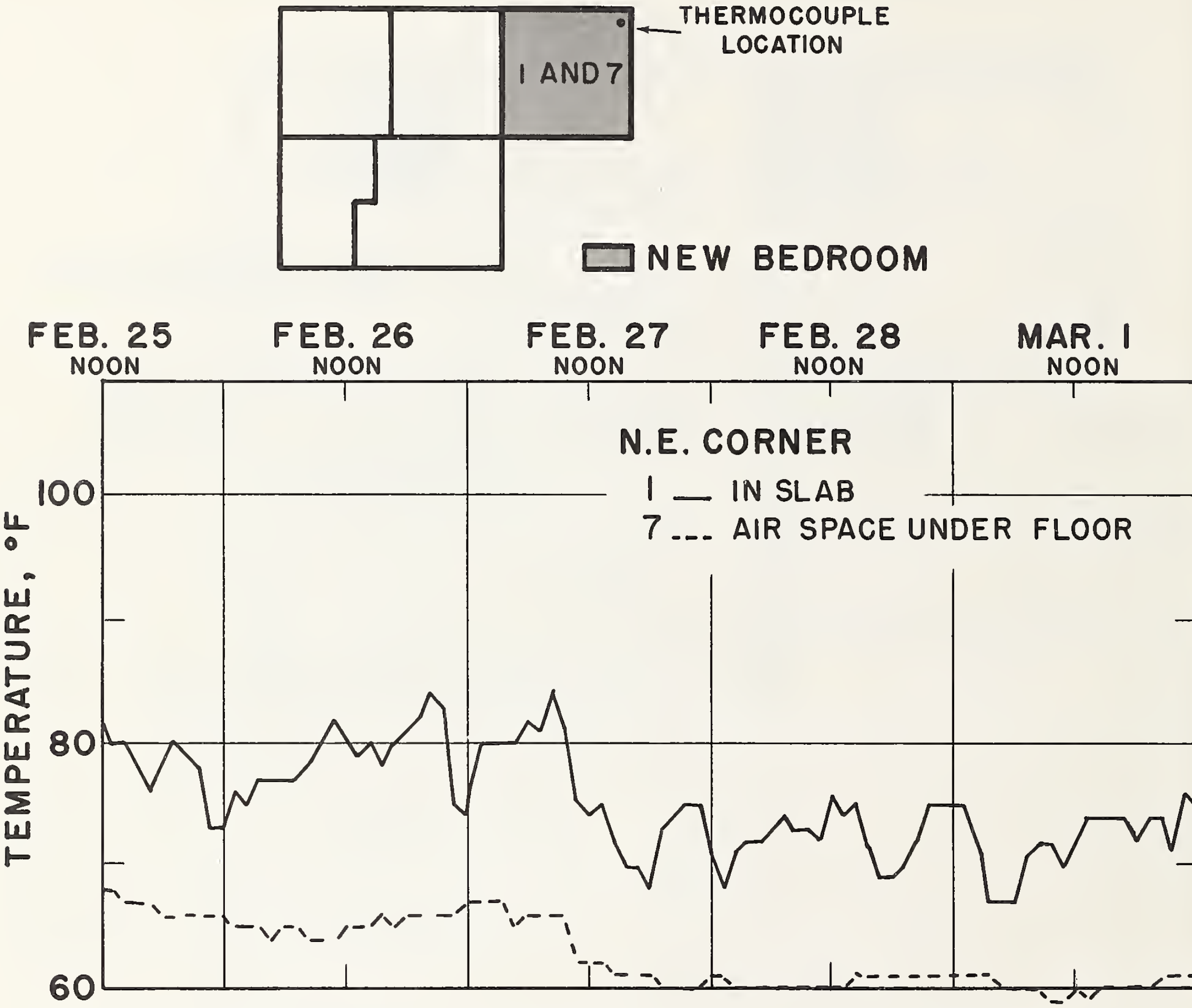

FIGURE 7.—Temperature in northeast corner of plenum chamber and in concrete slab immediately below it.

tures, but the room averages were about the same for both rooms.

When the same comparison was made between the center bedroom and the new bedroom, the differential between the temperatures at the 4-inch level and the 90-inch level was found to be about the same for both rooms (fig. 8, *B*). The temperatures maintained a stable daily cycle in both rooms; but the average temperature in the center bedroom was several degrees colder than that of the new bedroom.

When the temperatures of the new bedroom at the 4- and 90-inch levels were compared with those of the master bedroom, the differential was found to be about twice as large in the master bedroom (fig. 8, *C*). The temperatures in both rooms maintained a stable daily cycle with very little hourly fluctuation. The average temperature of the master bedroom was several degrees colder than that of the new bedroom.

Second-Season Tests

Testing procedure.—For the second season the walls of the center and the master bedrooms were insulated and finished inside. The wall construction was changed six times before it was completed, with each change constituting the basis for a new test. Throughout these tests, the walls of the bedroom addition were unchanged. The following list indicates the wall

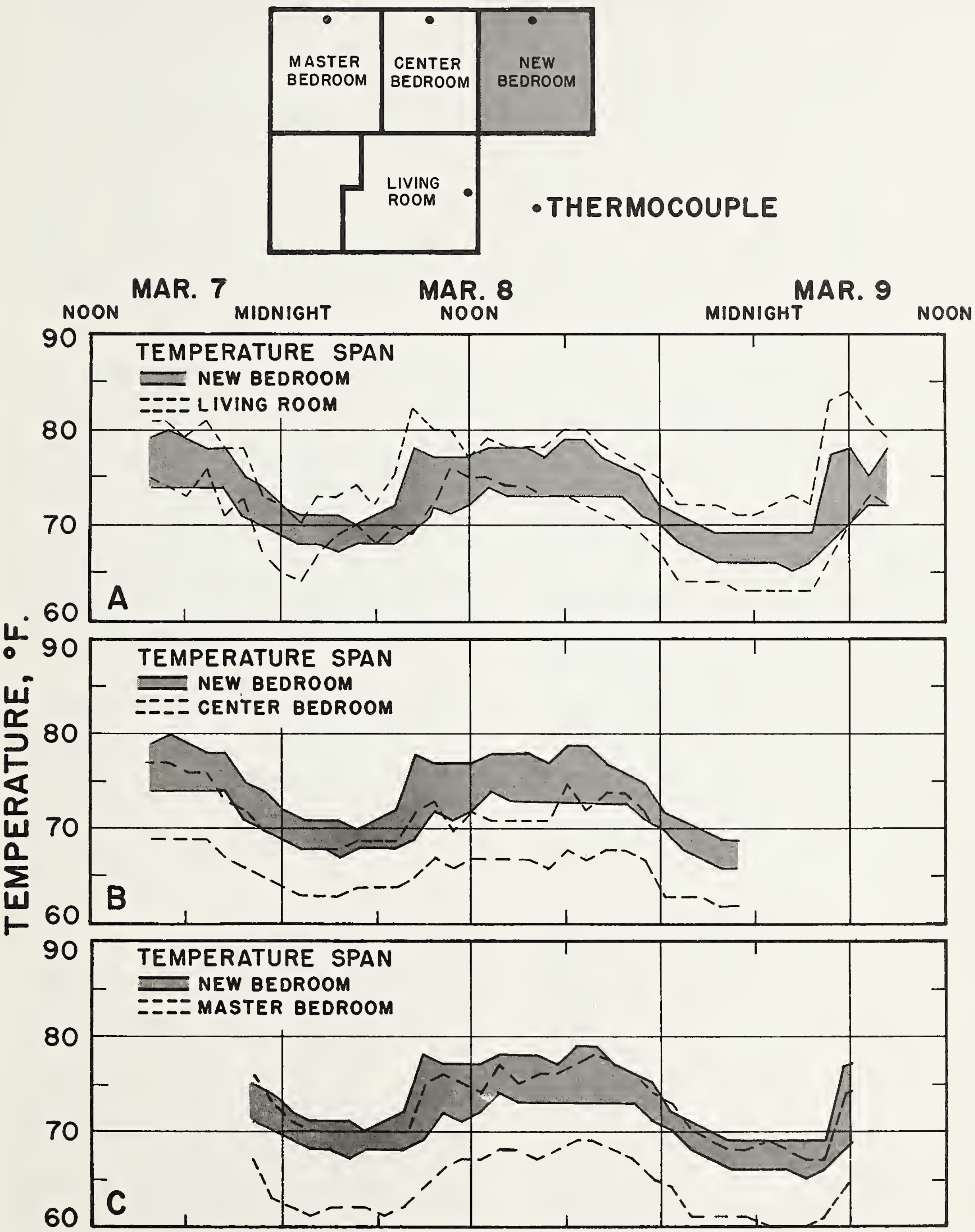

FIGURE 8.—Comparison of temperatures at the 4- and 90-inch levels in new bedroom with those in other rooms of house D: *A*, In living room; *B*, in center bedroom; and *C*, in master bedroom.

TABLE 1.—*Comparison of average temperatures in each of the 3 bedrooms at the 4-inch (floor), 48-inch, and 90-inch (ceiling) levels in each of the tests, and outside temperatures*

Wall treatment[1]	Outside temperature	Average temperature at floor			Average temperature at 48 inches			Average temperature at ceiling		
		Master bedroom	Center bedroom	New bedroom[2]	Master bedroom	Center bedroom	New bedroom[2]	Master bedroom	Center bedroom	New bedroom[2]
	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.
1	54.1	69.3	68.4	---	73.2	72.5	---	73.9	73.9	---
2	50.8	67.2	69.5	---	73.1	73.2	---	74.2	74.4	---
3	46.5	66.2	70.1	69.7	72.9	72.3	71.4	73.8	73.2	71.9
4	40.9	66.3	69.1	69.2	72.4	71.2	71.0	73.7	72.1	71.5
5	32.8	61.9	67.5	68.1	71.7	71.0	70.0	73.5	72.0	70.7
6	32.3	65.6	71.4	69.2	73.4	72.5	71.1	73.2	73.3	71.9
7	46.0	66.7	71.6	69.4	73.4	73.0	71.5	74.0	73.7	72.2

[1] See below for wall treatments of master and center bedrooms.
[2] See p. 4 for wall construction of new bedroom.

treatments of the master and center bedrooms for each of the seven tests.

1. Bare brick wall (no treatment).
2. One-inch furring with ½-inch Homosote finish
3. One-inch furring with ¼-inch Upson board finish
4. One-inch furring with ⅜-inch gypsum board finish
5. Master bedroom—2-inch furring with ¼-inch Upson board finish
   Center bedroom—1-inch furring with ⅜-inch gypsum board finish.
6. Master bedroom—2-inch furring with 2-inch wool insulation and ¼-inch Upson board finish.
   Center bedroom—2-inch furring with 2-inch wool insulation and ⅜-inch gypsum board finish.
7. Master bedroom—same as No. 6 except 4-mil. vapor barrier added.
   Center bedroom—same as No. 6.

Data were taken in the same manner and with the same equipment used for the first season.

Results of tests.—The average temperature in each of the three bedrooms at the 4-inch (floor), 48-inch, and 90-inch (ceiling) levels are given in table 1. At the floor level there was a radical difference in temperature from room to room. At the 48-inch level the temperature difference from room to room was only a few degrees, and at the ceiling level it was about the same in all rooms with little variation.

Data (table 1) on the average temperature 4 inches above the floor in the master bedroom and the average outside temperature indicate a direct relation between these inside and outside temperatures for the first five comparisons. For test No. 6, 2 inches of insulation were added to the master bedroom wall. The continuity of the relation was broken by the change in the thermal resistance of the wall, but it was regained and continued at a new relative differential.

Table 2 shows the comparison of the average temperature difference between the 4-inch (floor) and 90-inch (ceiling) level for the three bedrooms, with the outside temperature.

Figure 9 shows the average temperature spans between the 4-inch (floor) and 90-inch (ceiling) level in the center bedroom under treatments 1 and 2 and comparison of those in the center bedroom under treatments 3 to 7 with those in the new bedroom.

TABLE 2.—*Comparison of the average temperature difference between the 4-inch (floor) and the 90-inch (ceiling) level for the 3 bedrooms, with the outside temperature*

Wall treatment[1]	Average temperature difference from floor to ceiling			Outside temperature
	Master bedroom	Center bedroom	New bedroom[2]	
	°F.	°F.	°F.	°F.
1	4.6	5.5	--	54.2
2	7.0	4.9	--	50.6
3	7.6	3.1	2.2	46.5
4	7.4	3.1	2.3	40.9
5	11.6	4.6	2.6	32.8
6	7.6	1.9	2.7	32.3
7	7.0	2.1	2.8	46.0

[1] See this page for wall treatment of master and center bedrooms.
[2] See p. 4 for wall construction of new bedroom.

In the master bedroom there was no relation between the temperature differential and the outside temperature when the outside temperature was above 40° F. (table 2). However, when the average outside temperature dropped below this level, the differential seemed to increase rapidly. After the wall was insulated with 2 inches of batt insulation, there seemed to be no relation at temperatures as low as 32°.

TABLE 3.—*Comparison of the average temperatures at 4 feet above the floor and at the 90-inch (ceiling) level in each of the 3 bedrooms*

Wall treatment[1]	Average temperatures at 4-foot and ceiling levels and difference								
	Master bedroom			Center bedroom			New bedroom[2]		
	4 feet	90 inches	Δt	4 feet	90 inches	Δt	4 feet	90 inches	Δt
	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.
1	73.9	73.2	0.7	73.9	72.5	1.4	---	---	---
2	74.2	73.1	1.1	74.4	73.2	1.2	---	---	---
3	73.8	72.9	.9	73.2	72.3	.9	71.9	71.4	0.5
4	73.7	72.4	1.3	72.1	71.2	.9	71.5	71.0	.5
5	73.5	71.7	1.8	72.0	71.0	1.0	70.6	69.9	.7
6	73.2	73.4	−.2	73.3	72.4	.9	71.9	71.1	.8
7	74.0	73.4	.6	73.7	73.0	.7	72.2	71.5	.7

[1] See p. 10 for wall treatment of master and center bedrooms.

[2] See p. 4 for wall construction of new bedroom.

In the center bedroom (table 2 and fig. 9) there was a constant trend toward a lower differential as insulation was added. The effect of insulation is illustrated in tests 6 and 7 when the outside temperature was quite cold (table 2). The differential dropped from about 4.5 in test 5 to about 2.0 in test 6 and 7.

In the new bedroom no patterns were noticed (table 2 and fig. 9). At lower outside temperatures, the differential was smaller in the new bedroom than in the center bedroom until the center bedroom had an equal amount of insulation. Then the differential was about the same in both rooms.

Figure 10 shows the average temperature spans between the 4-inch (floor) and 90-inch (ceiling) level in the master bedroom under treatments 1 and 2 (p. 10) and comparison of those in the master bedroom under treatments 3 to 7 with those of the new bedroom. Also the differences between these temperatures are given in table 2. At all times during the tests the temperature difference between the floor and the ceiling in the master bedroom was greater than the temperature difference between the floor and the ceiling in the new bedroom (fig. 10 and table 2). As insulation was added to the walls in the master bedroom, the differential became smaller but remained larger than that of the new bedroom. The floor-level temperature fluctuated severely in the master bedroom during the cold days, but the ceiling-level temperature maintained a stable daily cycle.

Table 3 compares the average temperature at 4 feet above the floor with the temperature at the ceiling level in each of the three rooms. This shows that the temperature at the 4-foot level and that at the ceiling level was usually within 2°F. of each other.

Third-Season Tests

Testing procedure.—Tests conducted during the third season were designed to confirm the data from the two previous tests. The data were collected in the same manner as for the first two seasons.

Results of tests.—Figures 11 and 12 compare the temperature of the master bedroom and the new bedroom. In figure 11 the average temperature at 90 inches above the floor and the average temperature at 4 inches above the floor were plotted for the two rooms every 2 hours. The curve formed is similar to those of previous tests, which showed greater variation and fluctuation of temperature in the master bedroom with the perimeter-duct heating than in the new bedroom with the hot-air plenum.

To show that there were no extreme temperatures recorded in the room, figure 12 was plotted to show not the average but the maximum 90-inch temperature and the minimum 4-inch temperature recorded in each room at the same 2-hour intervals. This curve fluctuation is more severe than that of the average temperatures, but it is not much different from the average curve in figure 11. This indicated that the average temperature curve is representative of the whole-room temperature.

Evaluation of Tests

The different wall treatments did not greatly affect the temperature relations in the different rooms. However, some evidence of the effect of wall covering is found when the 2 inches of wool insulation were added to the master bedroom wall. The temperature at the 4-inch level rose several degrees with the outside temperature remaining near the same level. Another indication became evident when the temperature differential between the floor and the ceiling gradually became smaller as the insulation of the wall was increased in successive treatments.

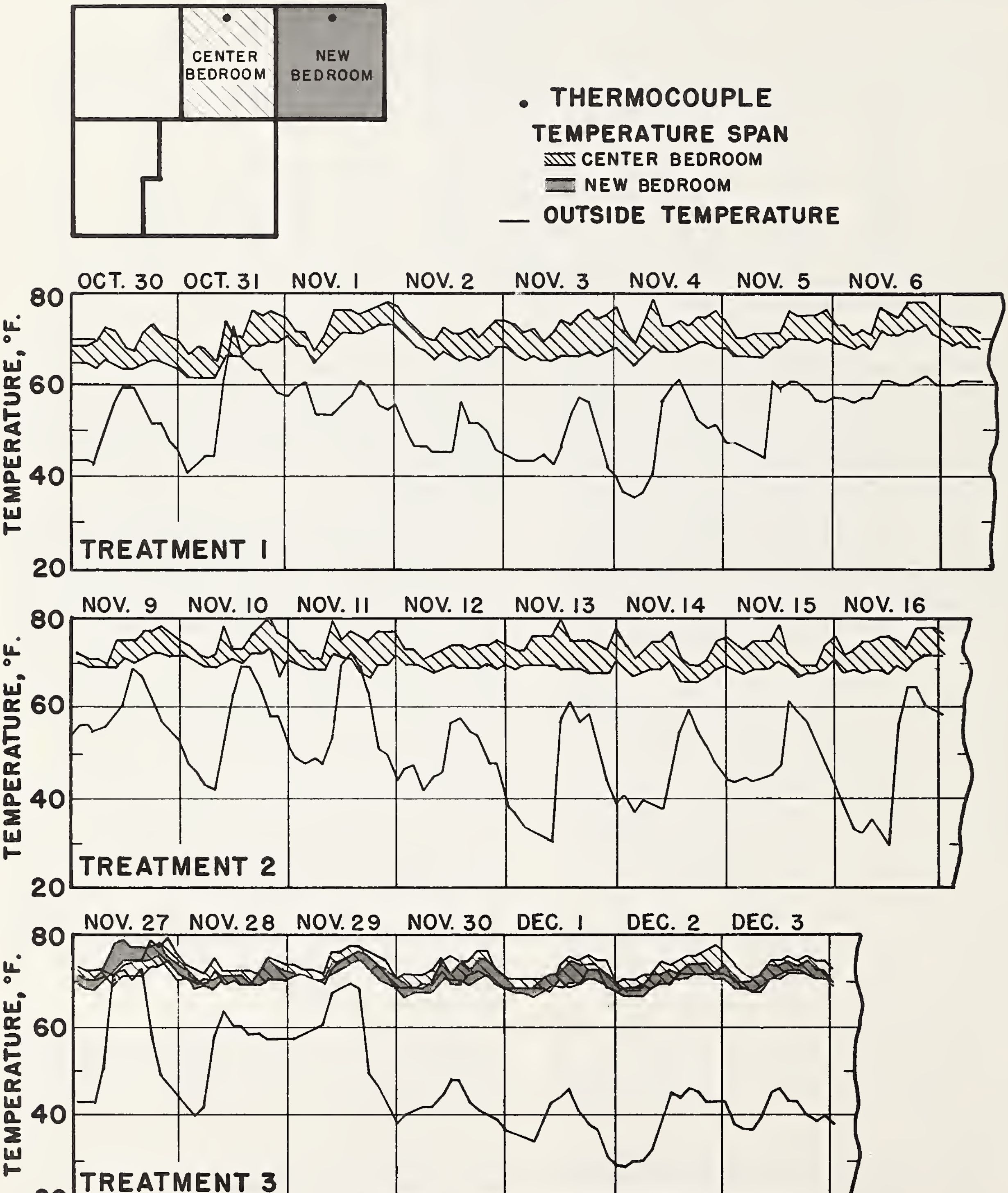

FIGURE 9.—Temperature spans between the 4-inch (floor) and 90-inch (ceiling) level in center bedroom under wall treatments 1 and 2 (p. 10) and a comparison of temperature spans in center bedroom under treatments 3 to 7 with those in new bedroom. Outside temperatures are also shown.

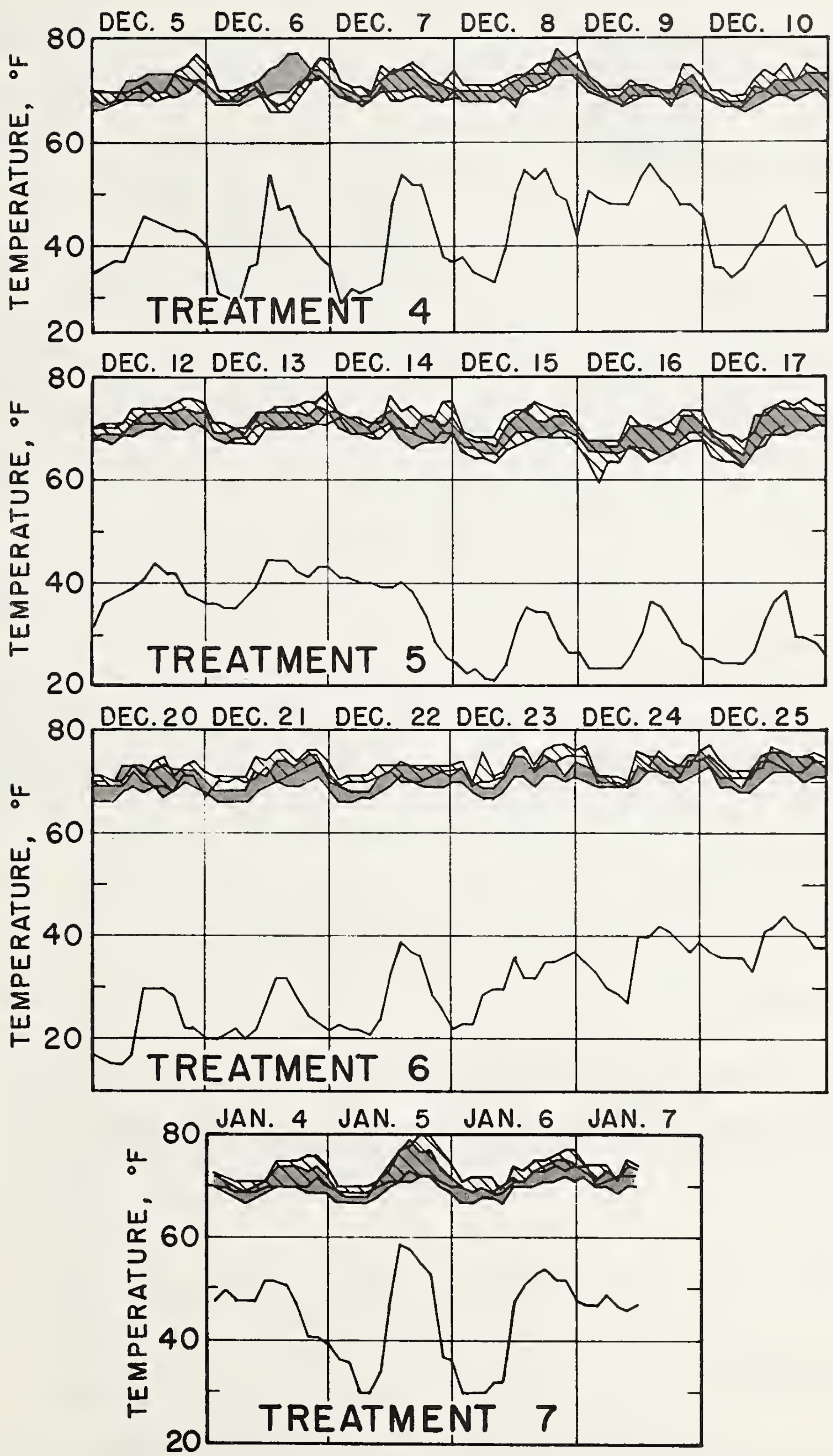

FIGURE 9.—Continued.

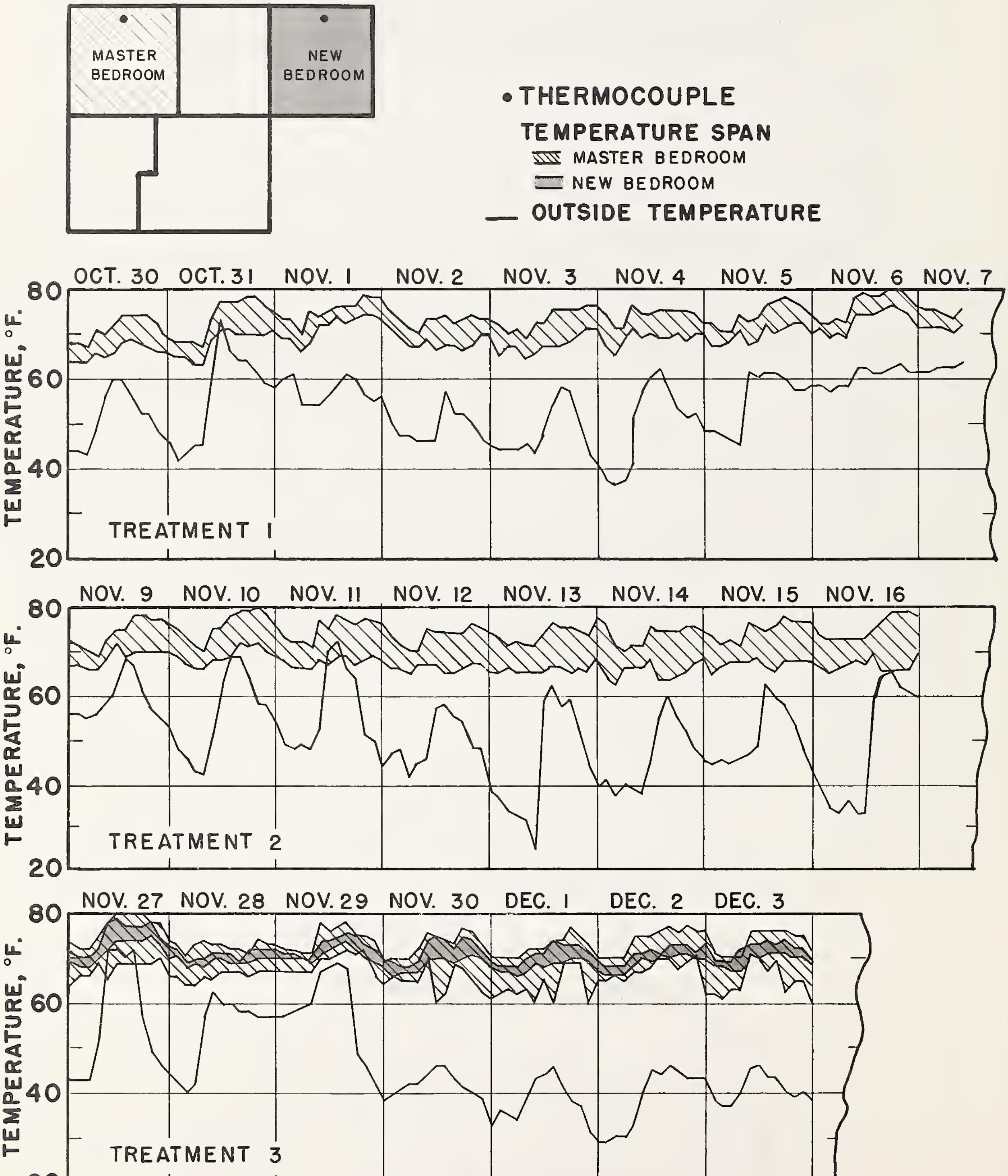

FIGURE 10.—Temperature spans between the 4-inch (floor) and 90-inch (ceiling) level in master bedroom under wall treatments 1 and 2 (p. 10) and a comparison of temperature spans in master bedroom under treatments 3 to 7 with those in new bedroom. Outside temperatures are also shown.

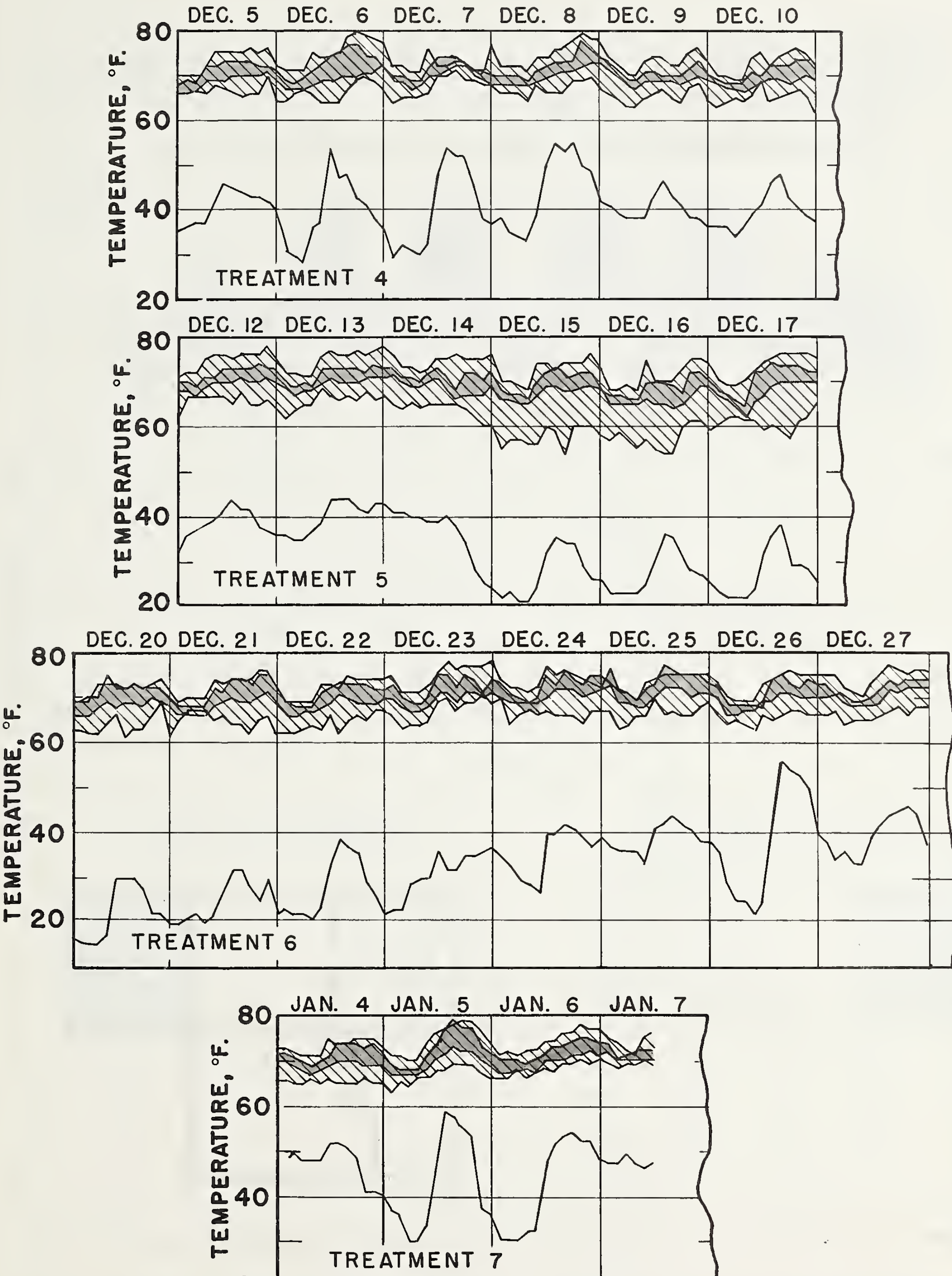

FIGURE 10.—Continued.

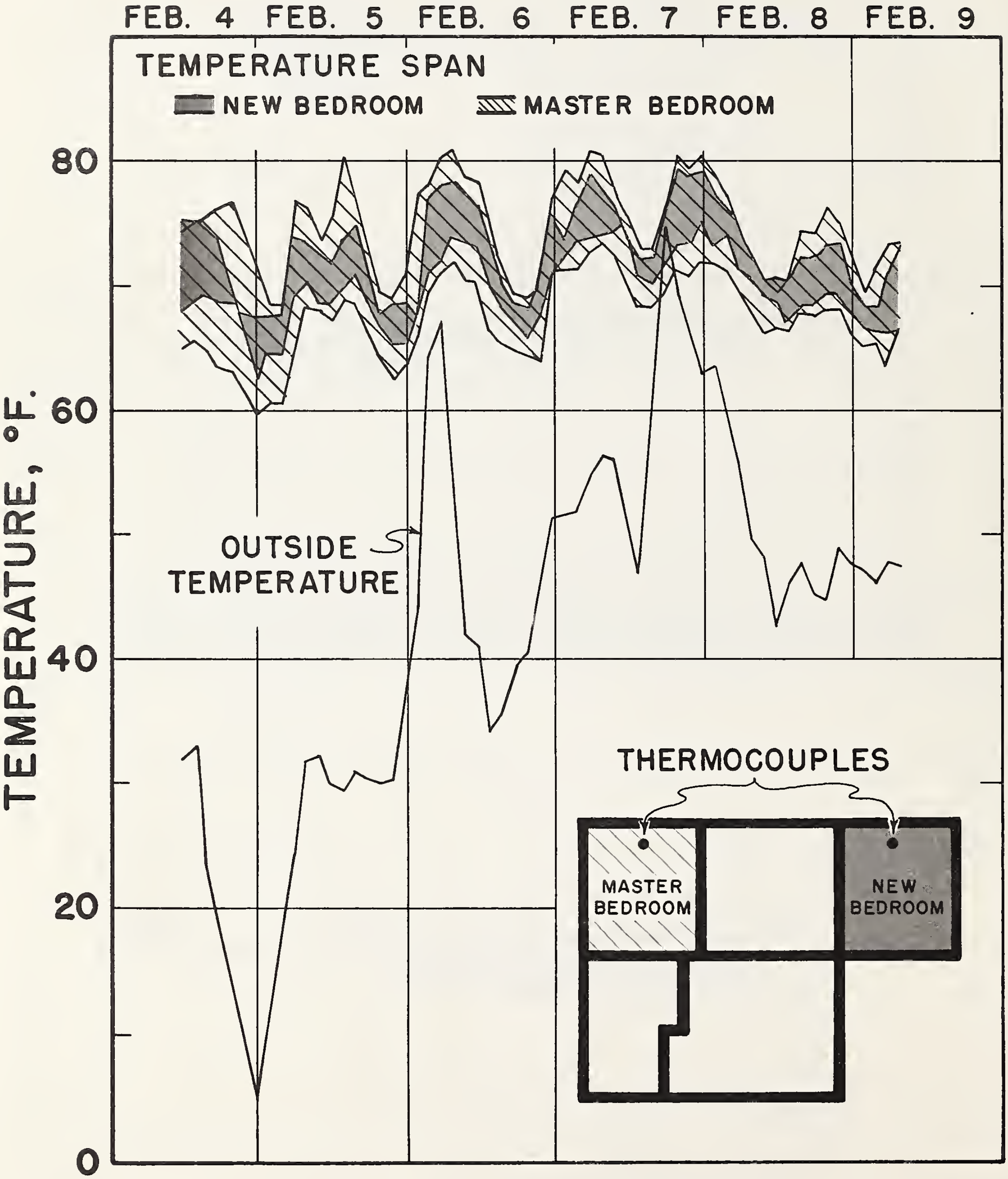

FIGURE 11.—Temperature span between the 4-inch (floor) and 90-inch (ceiling) level in master bedroom, with the perimeter-loop heating system, compared with that in the new bedroom, with the hot-air plenum system. Outside temperatures are also shown.

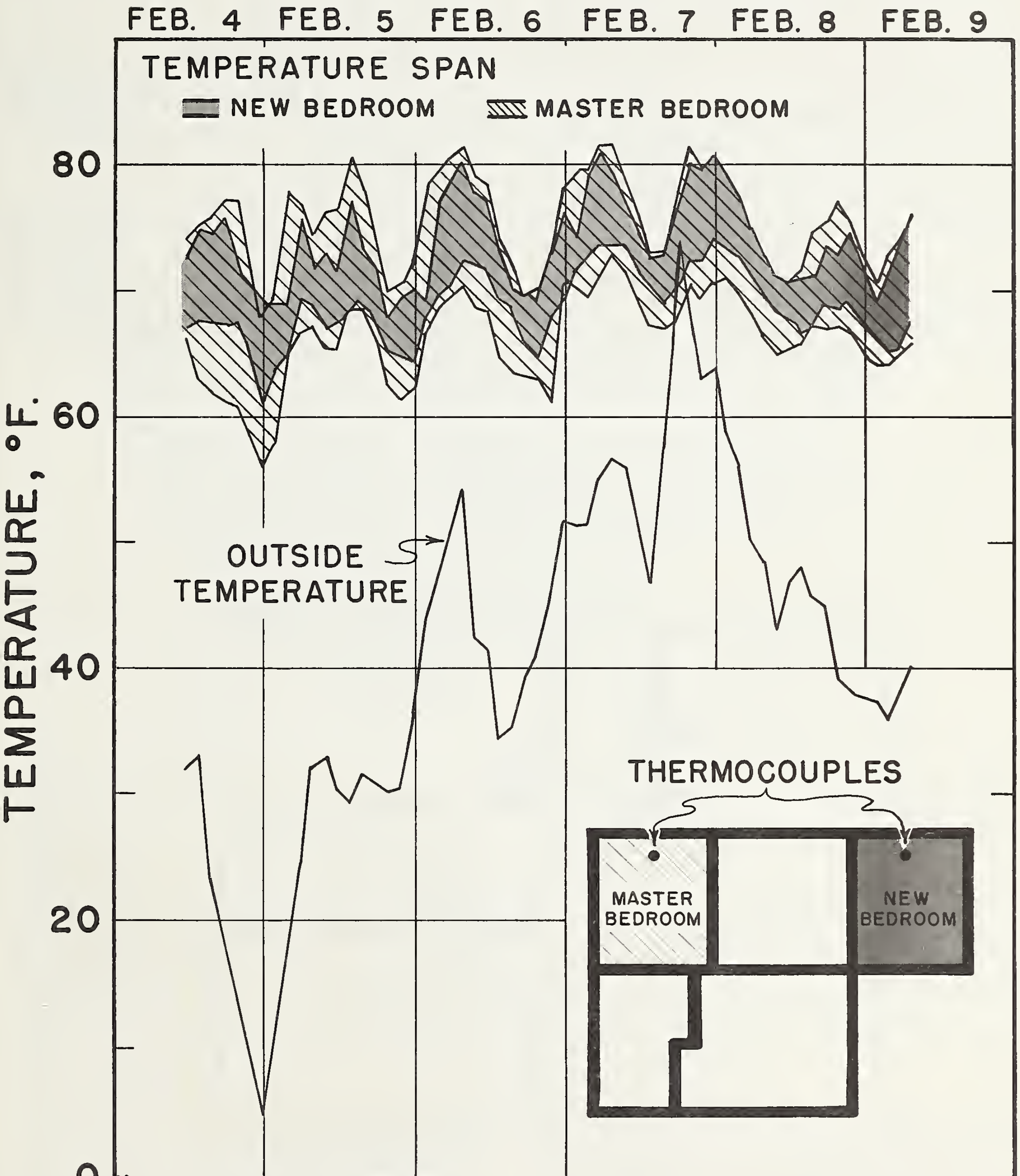

FIGURE 12.—Maximum temperature span in master bedroom, with the perimeter-loop heating system, compared with that in new bedroom, with the hot-air plenum system. Outside temperatures are also shown.

Outside temperature did not severely affect the inside temperature relations between the 4-foot and the ceiling level when the walls were well insulated (2 inches of batt insulation with inside and outside finishes). However temperatures at floor level tended to cycle with the outside temperature.

The difference in room performance is due to orientation, exposure, wall construction, and the heating system. But since the new bedroom has more wall exposure and the orientation is no better than the other roms, most of the differences can be attributed to the heating systems.

Crawl-Space Plenum

Since tests conducted in house D proved successful, plans were made to install a plenum to heat an entire house. The plenum was designed for a pole-frame house, 24 feet 8 inches by 33 feet in size, to be constructed at Charles Town, W. Va. (fig. 13).

This plenum differed from the one in house D in the following ways:

1. It served an entire house.
2. It was a crawl-space plenum (18 inches deep instead of 4 inches).
3. It used a plastic ground cover without the concrete slab.
4. The perimeter slot was wider.

Installation of Plenum

Figure 14 shows the plenum construction. It is constructed by placing nine 4-inch by 6-inch by 2-foot posts (built up from 2 by 4's) on concrete pads. These nine posts support three main beams that were built up from 2-inch by 8-inch timbers. These three beams support 2- by 6-inch floor joists placed 16 inches on center.

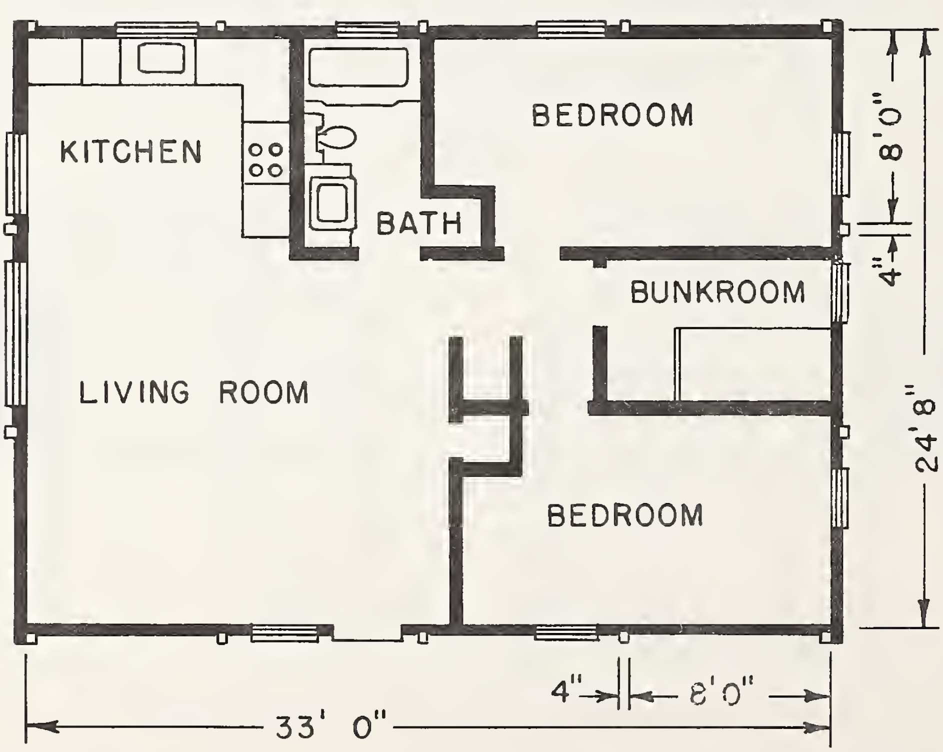

Figure 13—Floor plan of the house used for testing the crawl-space plenum, Charles Town, W. Va.

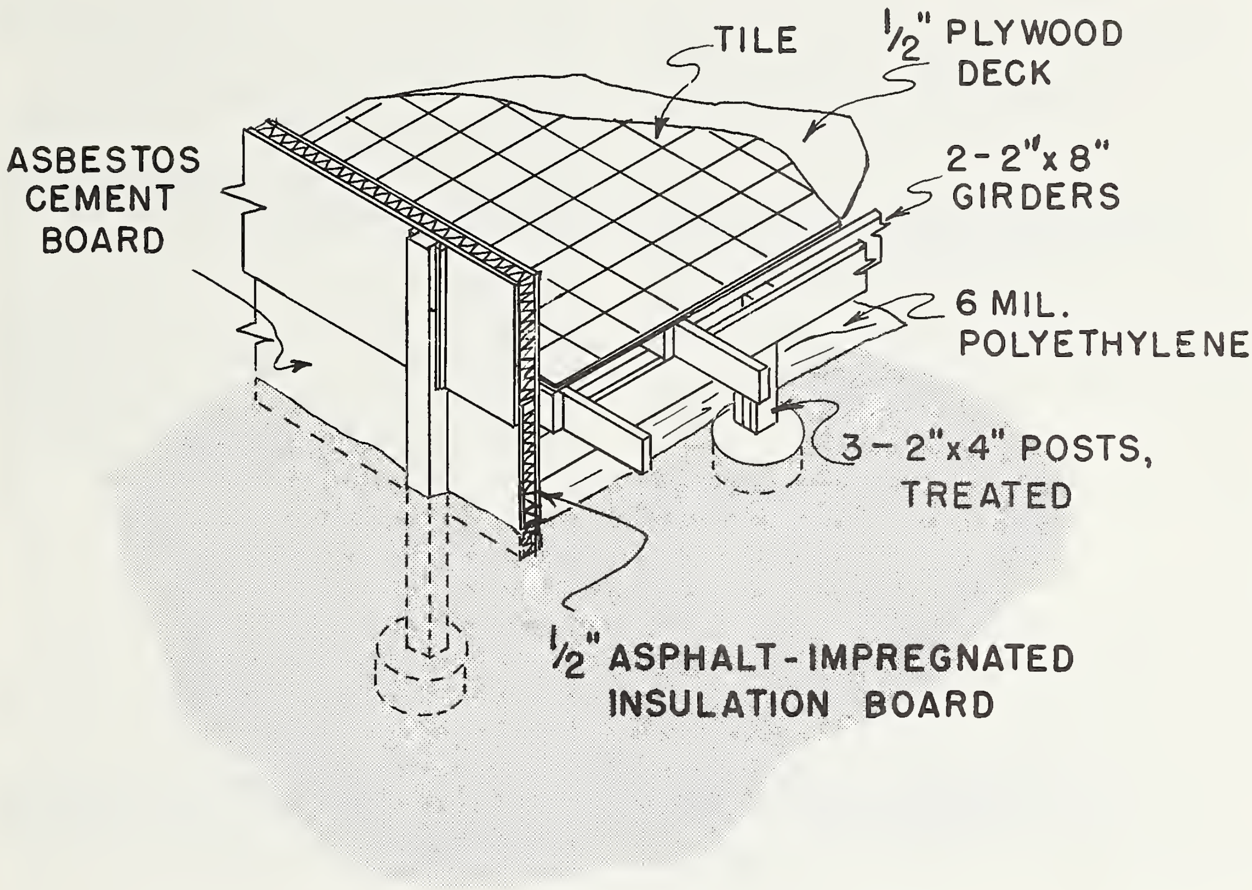

FIGURE 14.—Schematic of the crawl-space plenum construction.

The floor deck is ½-inch plywood with a decorative and wearing surface of ⅛-inch asphalt tile.

Heat was supplied to the plenum by a counterflow furnace, which was countersunk through the floor near the center of the house. Air taken into the furnace near the ceiling was blown over the furnace bonnet and discharged into the plenum. The air flowed unobstructed through the plenum to the perimeter of the structure where it was allowed to escape back into the living area through a slot in the baseboard.

Testing Procedure

The basis of comparison (temperature uniformity) for evaluating this heating system was the same as that used in house D. The temperatures were again measured at three elevations in each room (4, 48, and 90 inches above the floor). Identical telescoping aluminum poles were used to support the copper-constantan thermocouple sensing elements and the 16-point potentiometer was used to record the temperatures.

Objective of Tests

A series of tests was conducted in the house at Charles Town, W. Va., to determine the effect of various construction features on temperature uniformity from point to point at any particular time and from time to time at any particular point. Also a test was set up to determine the effect of reduced fan speed on temperature distribution.

Results of Tests

Examination of the data indicated that graphs showing the maximum and the minimum temperatures recorded in the house would most appropriately show the temperature uniformity with the various construction features.

The first test was conducted with baseboard installed in the living room only. A plot of the extreme temperatures in the house (fig. 15) shows that the temperature span was from 2° to 10°F. Much of this span is due to the irregular width of the perimeter slot from room to room. The temperature span within any one room was only about 2°, and the rooms with wider slot had higher temperature (not shown in fig. 15).

The second test was conducted with baseboard installed in all rooms except the bunkroom. A plot of the extreme temperatures in the house (fig. 16) shows a temperature difference of about 5° F. The reduction in the temperature span (compared with test No. 1) can be attributed to the more uniform perimeter slot.

A third test was conducted after the prime doors were hung to determine the effect of the additional insulation. Storm doors had been initially installed and the prime doors were hung at this time. The maximum temperature span was again about 5° F. (fig. 17).

Tests 4, 5, and 6 were conducted to evaluate the effect of window insulation on temperature uniformity. The temperature control throughout these tests was extremely uniform, and additional layers of plastic over the windows did not improve temperature uniformity (figs. 18, 19, and 20).

A seventh test was set up to determine the effect of reduced fan speed on temperature distribution. Although outside temperatures were extremely low, good temperature distribution was maintained with fan speed reduced to about two-thirds of its previous speed (fig. 21). The new airflow rate is about 600 cu. ft. per min.

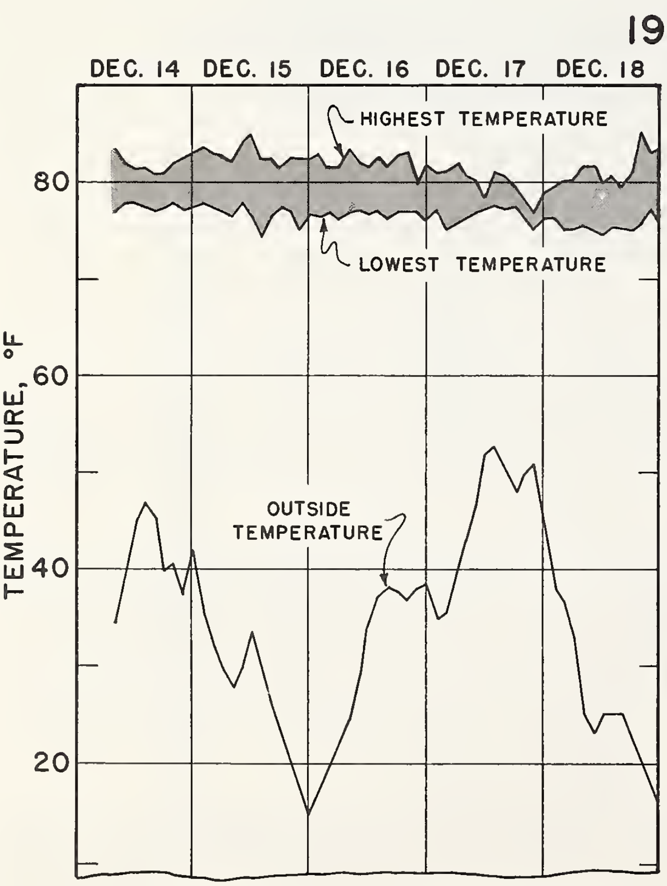

FIGURE 15.—Temperature span in the house at Charles Town, W. Va., when baseboard was installed in living room only. Outside temperatures are also shown.

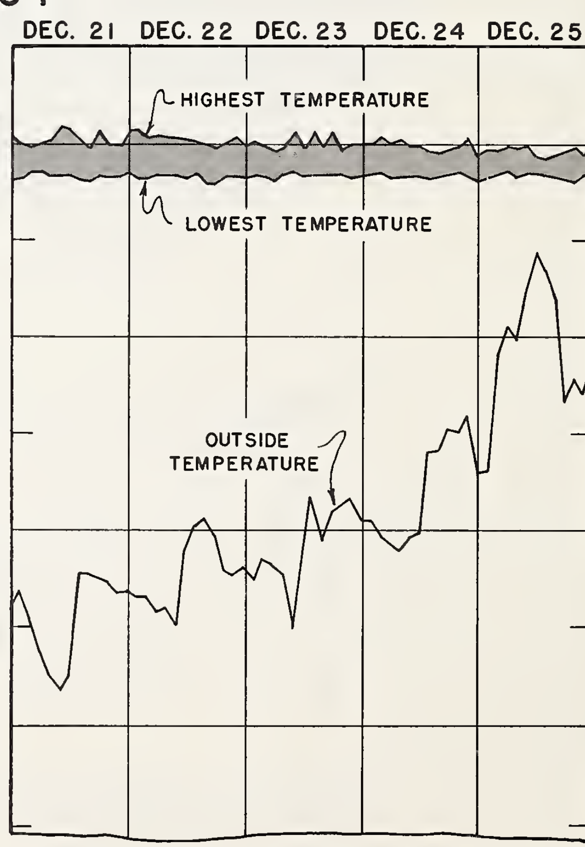

FIGURE 16—Temperature span in the house at Charles Town, W. Va., after baseboard was added in all rooms except the bunkroom. Outside temperatures are also shown.

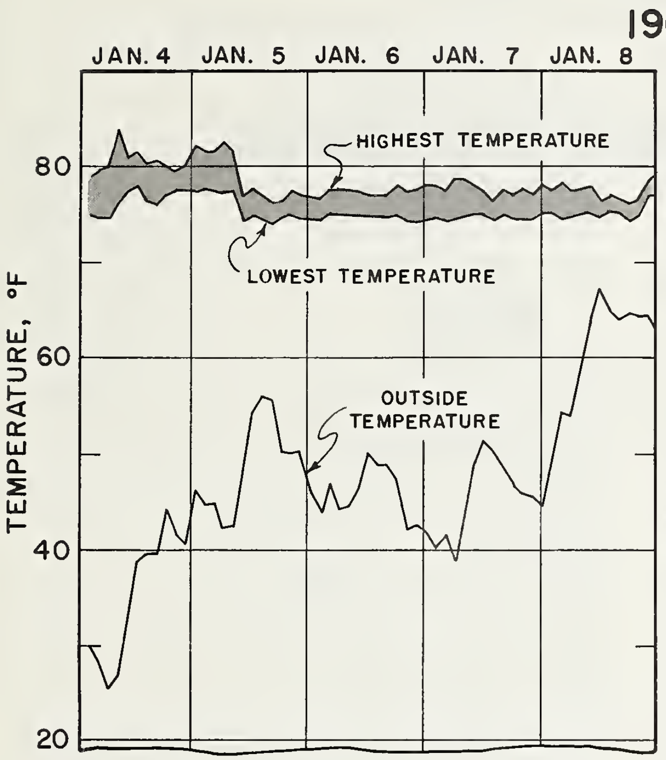

FIGURE 17.—Temperature span in the house at Charles Town, W. Va., with both prime doors and storm doors in place. Outside temperatures are also shown.

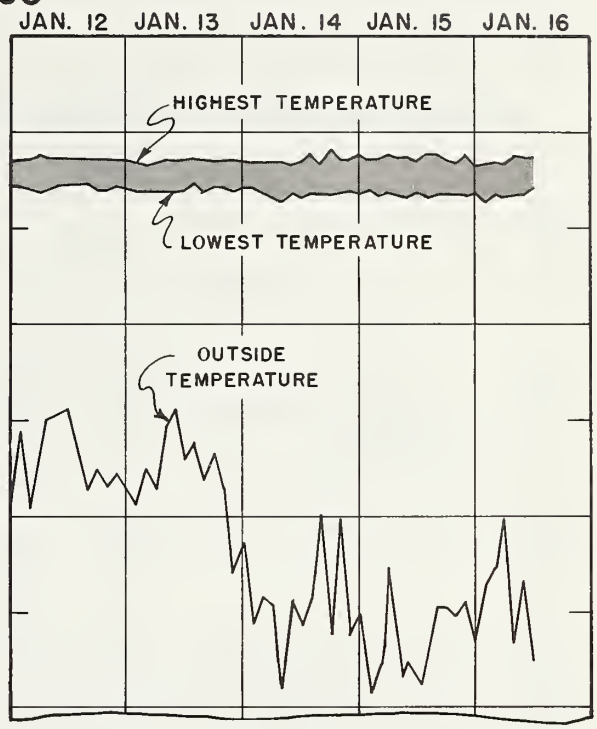

FIGURE 18.—Temperature span in the house at Charles Town, W. Va., after one layer of polyethylene was stretched over the windows. Outside temperatures are also shown.

Evaluation of Hot-Air Plenum

The hot-air plenum with a perimeter slot affords the occupants maximum comfort (uniform temperature distribution). The floor is a heat duct, thus cold floors are eliminated. Warm air from the duct (plenum) flows evenly up across the wall and maintains the wall near room temperature. At the same time the air is cooled so it does not appear as a blast of hot air. The perimeter slot diffuses the air into the room and distributes it evenly. Occupants are comfortable at lower temperatures with this system because less heat is radiated from their bodies to the walls and the floors. A hot-air plenum keeps the substructure warm and dry and eliminates freezing of water and sewer systems.

The National Fire Code places so many restrictions on a hot-air plenum that it is impossible to utilize the full potential of the system.

With the hot-air plenum the entire operation of the system is dependent on the blower operation; therefore, a failure of the electric system would cause failure of the heating system.

The house must be underpinned if it is to serve as a duct, or plenum. This will not be costly in the well-constructed house, which should be fairly tight except for ventilation vents. There will be a greater tendency to heat the soil with this system than with some other systems; thus, more fuel may be necessary. Another increase in fuel may be necessary, since more heat is lost through the sidewalls as the hot air flows up across them.

Another feature of this system that proved to be objectional was the absence of a warm spot in the house where persons coming in from outside could warm their hands or where persons could receive immediate heat while the house was heating up after a period of nonuse.

The $400.00 cost of the heating system is not expensive compared with most central heating systems; however, it may be beyond the means of the person building a low-cost house. In the test house it constituted one-seventh of the total cost.

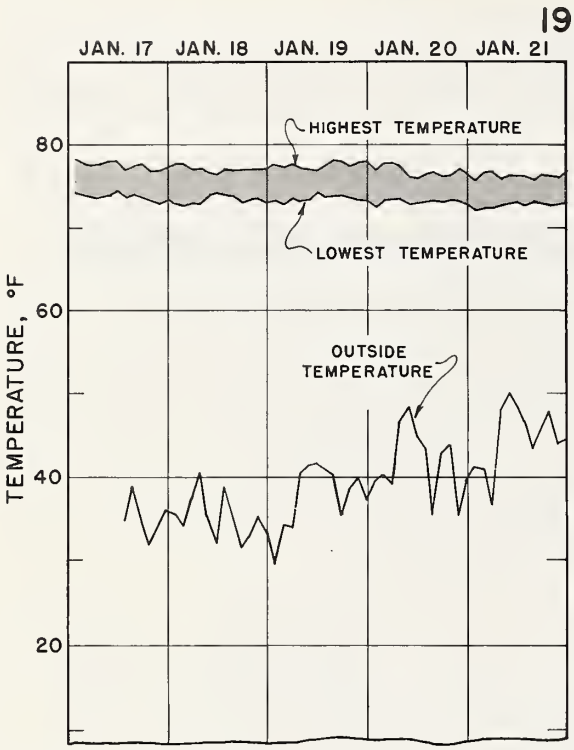

Figure 19.—Temperature span in the house at Charles Town, W. Va., after two layers of polyethylene was stretched over the windows. Outside temperatures are also shown.

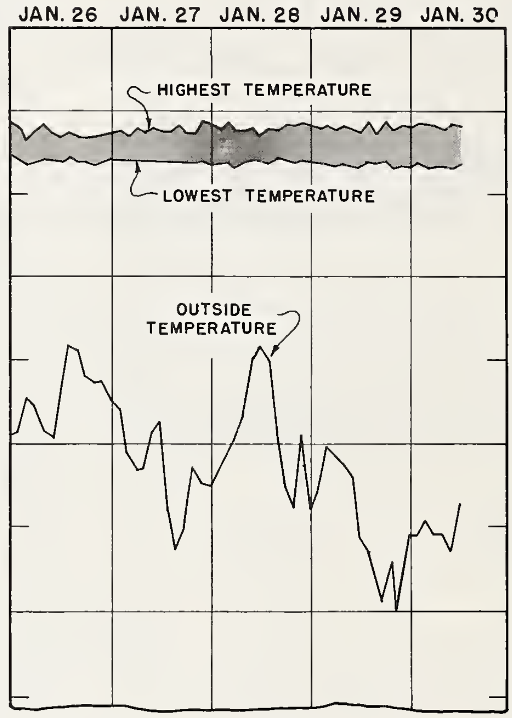

Figure 20.—Temperature in the house at Charles Town, W. Va., after three layers of polyethylene was stretched over the windows. Outside temperatures are also shown.

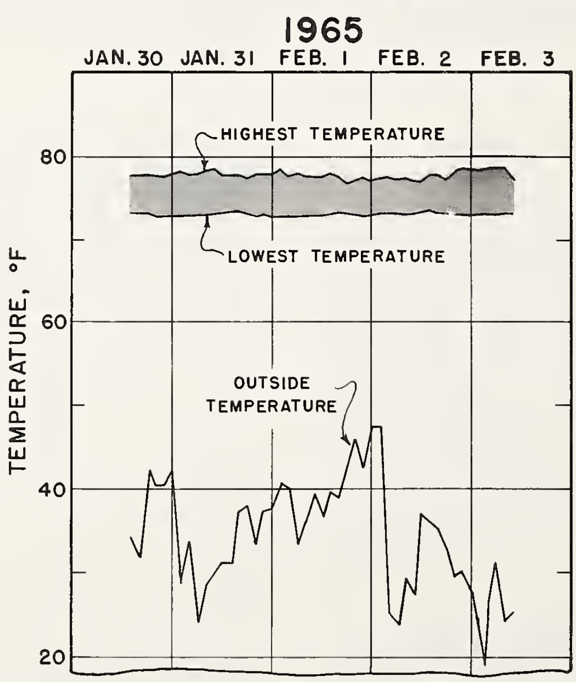

Figure 21.—Temperature span after fan speed had been lowered to 600 c.f.m. Outside temperatures are also shown.

CIRCULATION PLENUM

Justification and Description

In an effort to overcome some of the objections to the hot-air plenum a new concept of plenum use was initiated. The plenum was to be used as a circulation, or turbulation, center instead of a hot-air distribution center. Since the hot-air plenum already utilizes the plenum as a circulation center, the only change to be made in the system is the location of the heat source (fig. 22).

The use of the plenum as a circulation, or turbulation, center separates it from the heating system as such. It employs no temperatures above those normally found in the living area of the house and its association with the heating system is only incidental. For these reasons the circulation plenum brings the comforts of central heating to a house with a wood or coal radiant heater without the accompanying hazards of the hot-air plenum. Since this plenum only circulates room-temperature air throughout the plenum and the house and there is no flame or heat source as a part of this pattern, it does not create the need for the restrictions placed on hot-air plenums by the National Fire Code.

In the hot-air plenum the heat source is located so that most of the heat is injected directly into the plenum. If the heat source is removed from the air duct leading into the plenum and placed in another area of the house, then the plenum ceases to be a hot-air plenum or even a return duct. Its only function would be to circulate the air in the house. The purpose of this circulation would be to pull air from all sections of the house, mix it, and force it into the plenum for redistribution. This process should tend to cool warm areas and to warm cold areas in the structure. Therefore, a heat source at any location in the house will provide warm air for recirculation into the other areas of the house.

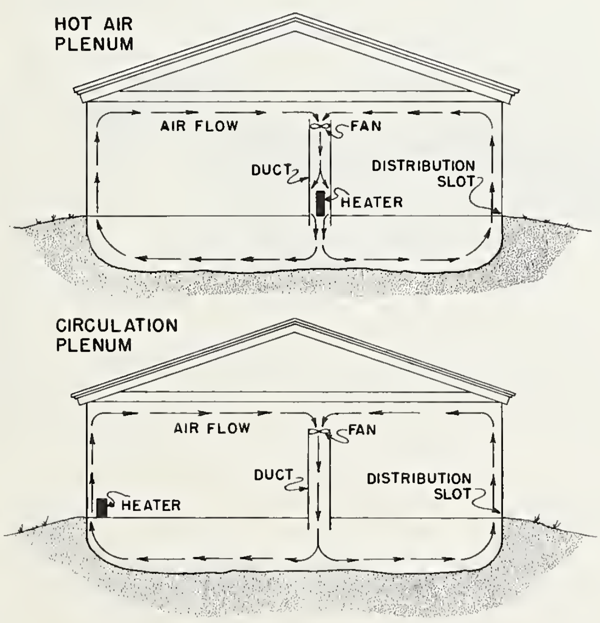

FIGURE 22.—Schematic of the hot-air plenum and of the circulation plenum.

Contrary to what one might imagine, the temperature distribution should be as uniform in the rooms with this heat source as it would be with a hot-air plenum. And there would be one hot spot or area in the house, which as previously indicated, may be desirable. If the blower operation should be interrupted by power failure, the system could still provide heat to part of the house. The furnace-type system would be of no value during a power failure.

The cost of the heating system could vary over a wide range. A simple wood or coal stove could easily serve as the heat source. Circulation could be accomplished with a blower mounted on a duct near the ceiling of the house that would collect air from the living area and force it into the plenum. A series of tests were set up to evaluate the circulation plenum.

An oil radiant heater was installed in prototype No. 1 at Charles Town, W. Va. The oil burner was shut off on the furnace, but the blower was allowed to operate continuously. This was the only change necessary to convert the house heating system from a hot-air plenum to a circulation-type plenum. The same instrumentation and the same method of evaluation as those used for testing the hot-air plenum were used for testing the circulation plenum.

Results of Tests

Figure 23 shows the extreme temperatures recorded in the house. The highest temperature was recorded at ceiling height in the room with the heater. Since this temperature was several degrees higher than the temperature at any other area of the house the second highest temperature was also plotted for comparison purposes. The irregular temperature at the ceiling of the living room is an indication of the high and low flame operation of the oil radiant heater. Examination of the original data shows the living room temperature at 4 inches and 48 inches above the floor was several degrees lower than the temperature at the ceiling. Evidently the air flowing through the perimeter slot picks up heat from the heater and rises to the ceiling. This warm air moves along the ceiling to the blower at the center of the house where it is mixed with air from the rest of the house and blown into the plenum. One can sense this heat stream by placing the hand near the ceiling. There is a sharp change in air temperature 6 to 8 inches below the ceiling. Most of the heat is being channeled to the plenum without overheating the living area.

NATURAL-CONVECTION CIRCULATION

In an effort to demonstrate the simplicity of the plenum circulation system and the independence of the heating source from the circulation system, a test was conducted in the test house at Charles Town without blower operation. This operation would be similar to that of a circulation plenum during a period of power failure. This would also be similar to that which might be used when only a small part of the house is to be heated from time to time. Although the heat source was controlled by an electric thermostat, an on-off manual control would produce the same relative situation.

In this test the high temperature was near the ceiling of the living room in the vicinity of the oil heater (fig. 24). Since this space was receiving heat directly from the heater, the second highest temperature was plotted for comparison purposes. Since the blower did not operate, the heat was moved slowly through the house. The heater operated in a more abrupt on-off cycle, which caused considerable variation in the living room temperature.

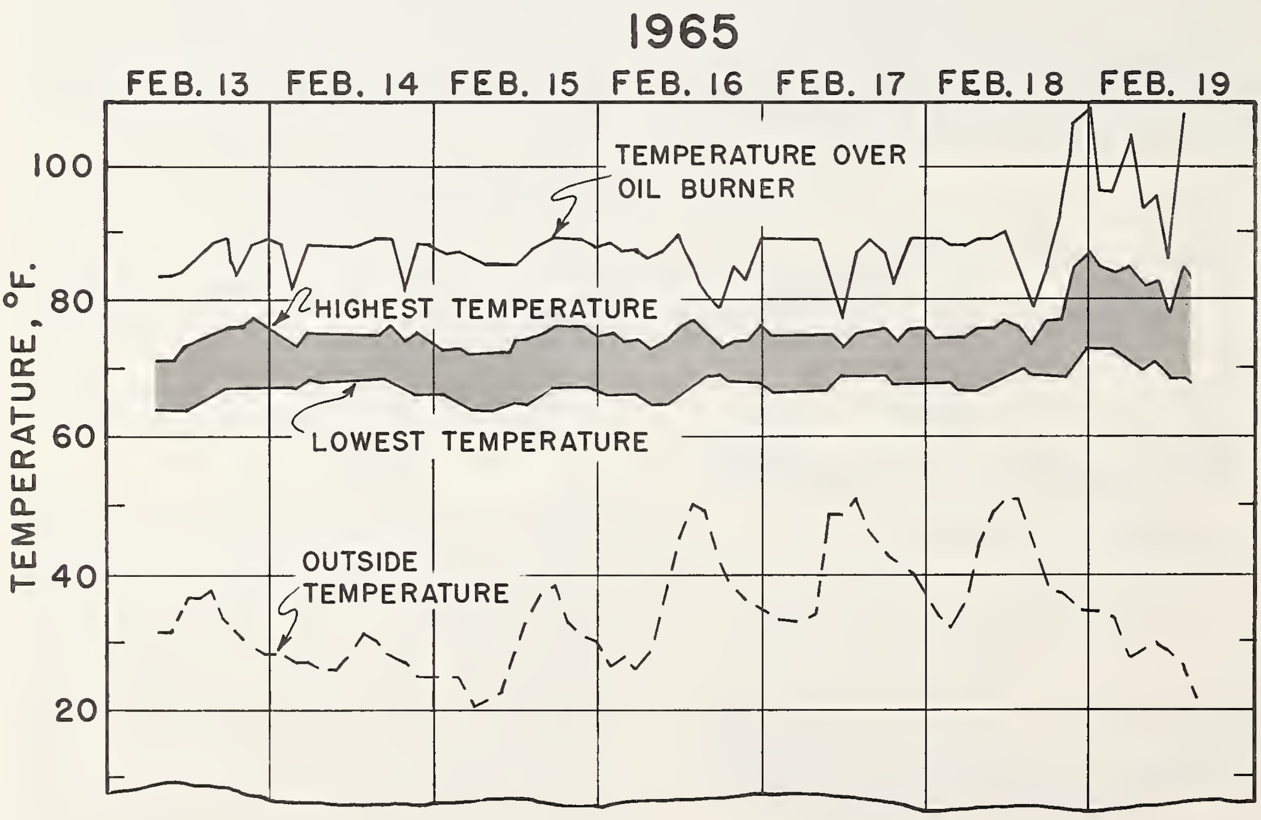

FIGURE 23.—Comparison of the highest temperatures in the house, except those over oil burner, and the lowest with circulation plenum; temperatures over oil burner are also given. Outside temperatures are also shown.

COMPARISON OF THE THREE HEATING SYSTEMS

Figure 25 shows the heat distribution for the three circulation systems: (1) hot-air plenum; (2) circulation plenum; and (3) natural-convection circulation. These graphs show the temperature spread at 4, 48, and 90 inches throughout the house for each heating system.

With the hot-air plenum (January 30 and 31, 1965) there is evidently little difference in temperatures from floor to ceiling; most of the variation is from room to room. One room with a proportionally large perimeter slot showed temperature 3° to 5° F. higher than the other rooms.

With the plenum circulation system (radiant oil heater) there is a greater temperature span, especially at the 4- and 48-inch elevations. The extremely high temperature over the heater is plotted here, but it must be disregarded for comparison purposes, since it is not representative of the 90-inch temperature in most areas of the house and this air has not been circulated through the system. Examination of the graph (fig. 25, *B*) shows that there is some indication of stratification but that this is very limited.

The natural-convection system shows definite stratification of the house temperature. Here the temperature span at 4 and 48 inches is much larger than it was in the other tests. This indicates that heat is reaching some areas of the house fast enough to maintain the temperature while supplying the losses, but in other areas the temperature level is not being maintained. Heat distribution is best at the 90-inch (ceiling) level. Here there is little variation from room to room at any one time, but because of the slow movement of heat away from the heat source the on-off operation of the heater causes considerable fluctuation in the ceiling temperature from hour to hour. The 90-inch (ceiling) temperature over the heater was exceedingly high when compared with other 90-inch temperatures; therefore, although it was plotted, it should not be used for comparison purposes because it is not representative of 90-inch temperatures throughout the house. The second highest 90-inch temperature was plotted for this comparison.

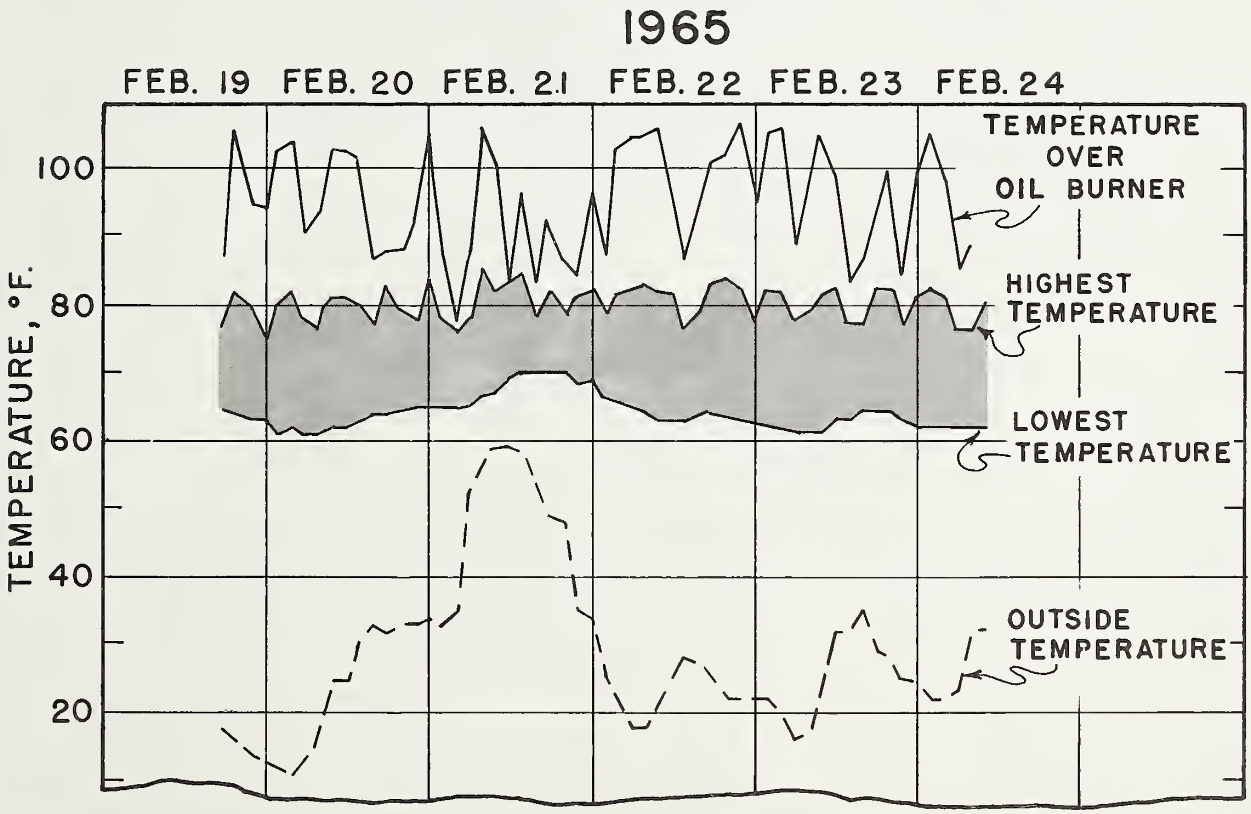

FIGURE 24.—Comparison of the highest temperature in the house, except those over oil burner, and the lowest with natural convection circulation; temperatures over oil burner are also given. Outside temperatures are also shown.

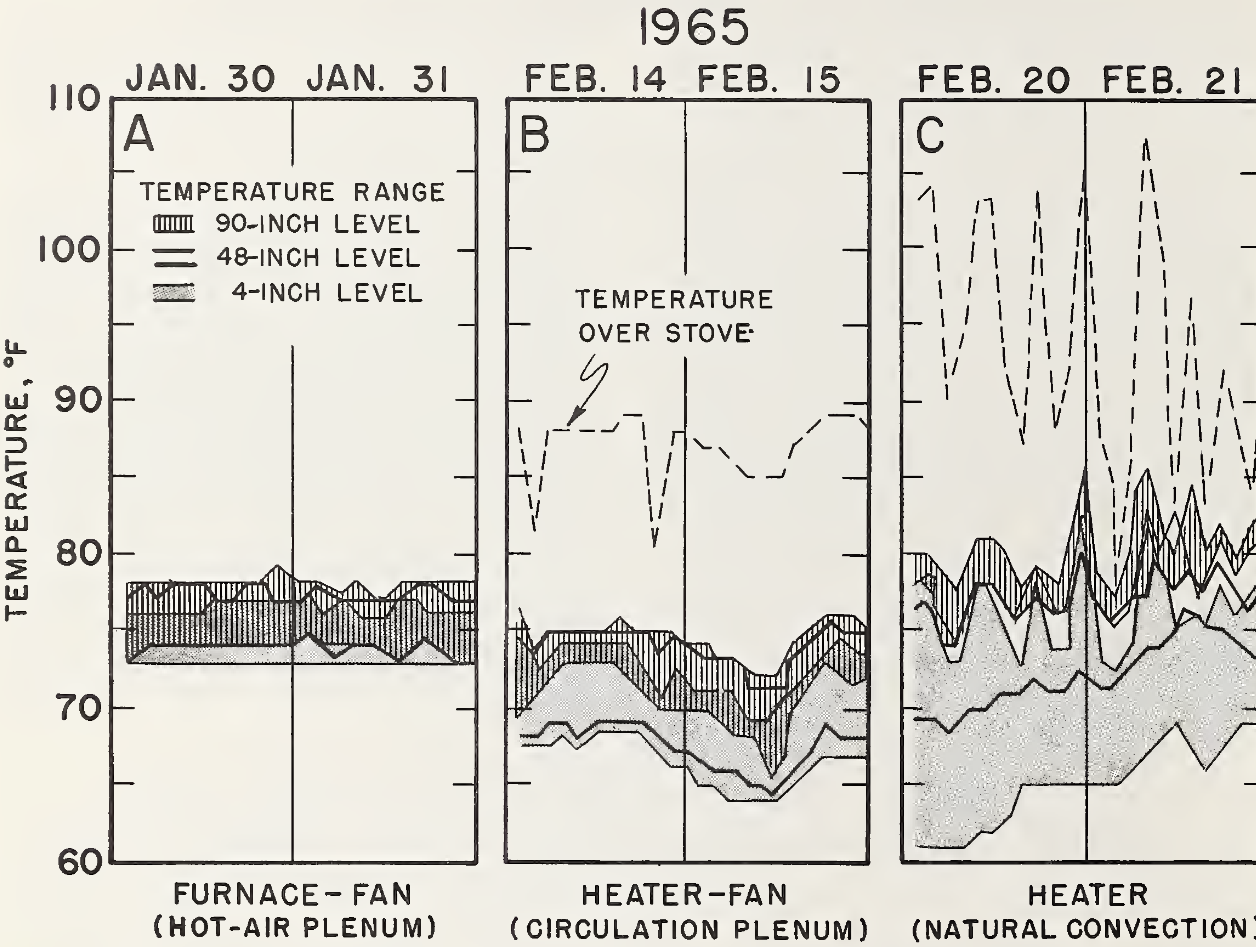

FIGURE 25.—Temperatures during 2 days under the three heating systems described in this report: *A*, Hot-air plenum; *B*, circulation plenum; *C*, natural-convection circulation.

CONCLUSIONS

Tests conducted in house D at the Agricultural Research Center and in prototype house 1 at Charles Town, W. Va., have shown that a hot-air plenum can give excellent temperature distribution if the inlets into the rooms are properly sized. The slot size is not a critical factor. The only rooms that became much warmer than the others were those with slot openings two or three times wider than those in other rooms.

The constant circulation of air has given excellent distribution in the individual rooms. Usually the temperature range from floor to ceiling in a room is not over 2° F.

The circulation plenum has been found almost equally as good as the hot-air plenum. Its hot spot for quick warm up, its lower cost, its independence from public utilities, and its aesthetic appeals are advantages that outweigh the slightly more uniform distribution with hot-air plenum.

If there were no need for heat in rooms other than that with the heat source, it would not be necessary to operate the blower with the circulation plenum.

More installations are needed to properly test this new concept of heating. Future tests should be directed toward houses with basements to determine the feasibility of a basement as a plenum. With the low plenum temperatures recorded in these tests (80°–90° F.), there seems to be no reason why the basement could not function as a plenum. With the circulation plenum only room-temperature air will be circulated therefore this would not be a part of the heating system. It would function much like a forced-air ventilation system (attic fan, window fan, exhaust fan).

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